LARSON

Stresses in the Web Reinforcement of Restrained Concrete Beams

Theoretical & Applied Mechanics

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1917

STRESSES IN THE WEB REINFORCEMENT OF RESTRAINED CONCRETE BEAMS

BY

LOUIS J LARSON

B. S. University of Minnesota, 1914

C. E. University of Minnesota, 1915

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN THEORETICAL AND APPLIED MECHANICS

IN

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June 2, 1917

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY LOUIS J LARSON

ENTITLED STRESSES IN THE WEB REINFORCEMENT OF RESTRAINED CONCRETE BEAMS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN THEORETICAL AND APPLIED MECHANICS.

A N Talbot
~~In Charge of~~ Thesis

A N Talbot
Head of Department

Recommendation concurred in:*

______________________	Committee
______________________	on
______________________	Final Examination*

*Required for doctor's degree but not for master's.

C O N T E N T S.

I. INTRODUCTION.

LIST OF FIGURES.

LIST OF CURVES.

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1. Preliminary. - The subject of web stresses in large continuous reinforced concrete beams has been investigated by several different experimenters. At the Experiment Station of the University of Illinois Messers. Hargis and Gonnerman tested beams of the same general dimensions as the specimens used in this thesis. After studying the results of previous experiments it was found that there were certain phases of web action about which very little was known. Nothing had been done to determine the effect on the web stresses of bending down bars at different angles. Also the permissible distance from the support or load point to the first bent down bar or stirrup and the spacing of the bent down bars and stirrups had been found by theory only and was not verified by actual tests. These points have been the source of many heated discussions by committees on Building Ordinances and Specifications and, while each committee naturally came to some conclusion by a majority rule law, ordinances still differ materially. Any series of tests therefore that would settle one or more of these points would certainly be worth while and it was with this in view that the present work was undertaken.

2. Scope. - The series of tests as finally decided upon consists of one set of beams differing only in the angle at which the bars were bent down, another set in which the spacing between bars was varied and a third set in which the angle and spacing was constant but the distance from the support to the first bend differed. As far as possible in all of the above cases the number of bars bent down at any point and the total number of bars bent down in the beam was constant. To provide for the bending moments

at all sections of the beams without the use of additional bars it was found necessary to bend down more than the usual number member at a given point in some cases. The permissible distance from the support to the first bend or stirrup was investigated for two different angles and for vertical stirrups, and the spacing between bends for the two steeper angles of bend.

In addition to the beams mentioned above some were made having one half the bars down at one point and the rest straight, without stirrups. Beams, called plain beams, were made in which there was no steel crossing the web. The latter were primarily auxiliary tests pieces to indicate the web strength of the concrete used and without which it would be impossible to find how much any type of reinforcement increased the web strength. One beam, with its duplicate, was also built which had three fourths of the bars down at the point of inflection. This was expected to fail near the support by diagonal tension at about the same load as the plain beam.

There were 21 different kinds of beams with a duplicate of each making 42 beams in all.

3. Acknowledgement. - The tests were made in the Laboratory of Applied Mechanics of the University of Illinois. The writer is indebted to Prof. A. N. Talbot, Professor in charge of Theoretical and Applied Mechanics, for his general supervision and advice in planning and making the tests and for his helpful suggestions in interpreting the results; to Prof. W. A. Slater for his assistance in planning the tests, suggestions on reducing the data, and for his helpful criticisms of the thesis; to Mr. H. F. Connerman, Research Assistant in the Experiment Station, for his assistance in plan-

ning the tests for his careful supervision and direction of the fabrication of the test specimens and for his untiring and willing assistance in the testing of the beams, and in the preparation of this thesis.

The writer also wishes to express his appreciation to R. L. Templin, Research Fellow in the Engineering Station for his cooperation in the preparation of apparatus used in the fabrication and testing of the beams and to B. Pepinsky for the careful and willing assistance in making the tests.

4. Theories and Formulas for Web Stresses. - The analysis of the web stresses in a homogeneous beam is comparatively simple. For a concrete beam having steel reinforcement and one or more cracks in the concrete across the web any attempt to calculate the web stresses will be extremely complicated and the results will be uncertain. Turneaure and Maurer , Taylor and Thompson and Hool among others give the formula $P = \frac{Vs}{jd}$ for vertical stirrups. In this formula $P =$ total load to be carried by the stirrups, $V =$ portion of total shear to be carried, $s =$ horizontal spacing of stirrups. For web reinforcement inclined at 45 deg. this formula is modified to read $P = 0.7 \frac{Vs}{jd}$. The reduction in the stress in a reinforcing member may be justified by the fact that the inclined web members cross the crack at shorter intervals, that is the distance between the inclined bars along the crack is less than between vertical stirrups of the same horizontal spacing. If the cracks form at 45 deg. and the reinforcement makes an angle of 45 deg. with the horizontal, the distances between the rods as measured along the crack is s sine 45 degrees. . For bars inclined at an angle, α, less than 45 deg. the expression $\frac{Vs}{jd}$ is

multiplied by sin α. This is not entirely accurate since the distance between inclined bars measured along a 45 deg. crack does not vary with sin α but for angles of inclination greater than 20 degrees the error is not any larger than those which other uncertainties introduce.

The Joint Committee on Concrete and Reinforced Concrete in its final Report in 1916 recommends the use of the formula $P = \frac{3}{4}\frac{Vs}{jd}$ for bars bent down at all angles from 20 to 45 deg. The proportion of the total shear to be used is not specified.

Using as the value of V in any of the above formulas the total shear in the beam gives higher stresses than are found from tests. About two-thirds of total shear seems to give reasonable results.

Another method of attacking this problem of web stresses is to pass a vertical section at the point at which stresses are to be determined. The vertical component of the total stress in the steel cut by this section must then be equal to the external shear at this point. Using the notation given above $P = \frac{V}{\sin \alpha}$. This formula gives very high stresses for bars bent at a flat angle even though only two-thirds of the total shear is used.

II. MATERIALS, TEST PIECES, APPARATUS, AND METHOD OF TESTING.

5. Materials. - The materials used were similar in character to those used on any high grade construction. All were of good quality and in excellent condition.

Cement. - Universal Portland cement giving strengths as shown in Table 1 was used.

TABLE 1.

TENSILE STRENGTH OF CEMENT.

Sample Numbers.	TENSILE STRENGTH IN LB. PER SQ. IN. AT AN AGE OF					
	7 DAYS.			28 DAYS.		
		1:3 MORTAR.			1:3 MORTAR.	
	Neat.	Stand. Sand	Attica Sand	Neat.	Stand. Sand	Attica Sand.
1	560	-		793	-	
2	640			636		
3	592	242	326	735	355	476
4	630	223	379	780	272	537
5	654	234	271		317	437
6		233	343		377	463
7		230	332		329	416
Average.	615	232	333	736	318	465

Sand. - The sand came from Attica, Indiana. The Sieve Analyses given in Table 2 show the grading of the sand.

TABLE 2.

MECHANICAL ANALYSES OF SAND.

Sample Number.	PERCENT PASSING SIEVE NUMBER.							
	3	4	8	14	28	48	100	Pan
1	99.5	97.0	73.7	42.2	17.5	6.8	2.7	0
2	99.4	96.4	76.1	48.2	22.0	9.2	4.0	0
3	99.6	97.1	76.5	47.5	22.3	10.5	5.0	0
4	98.8	96.8	75.2	45.7	19.8	8.0	3.8	0
5	95.7	93.3	71.6	43.3	18.7	6.1	0.2	0
6	99.2	90.7	53.4	29.4	10.6	4.8	1.8	0
7	97.9	94.2	67.7	37.7	14.2	4.4	1.1	0
8	98.0	95.1	71.5	40.7	16.7	6.2	1.8	0
9	98.1	95.2	73.0	44.0	18.7	7.5	3.1	0
10	99.5	97.1	75.0	44.3	19.3	7.9	24.0	0
Av.	98.6	95.3	71.4	42.3	18.0	7.1	2.6	0

Gravel. - A hard, washed gravel from near the Wabash River at Attica, Indiana was used. In size it varied from ¼ in. to 1 in., and the proportion of various sizes is given by the sieve analyses in Table 3.

TABLE 3.

MECHANICAL ANALYSIS OF STONE.

Size of Mesh.	PERCENT PASSING. SAMPLE NUMBER. 1	2	3	4	5	Av.
1"	100.	99.1	99.7	100.	100.0	99.4
¾"	79.8	71.6	71.5	70.5	71.3	72.9
½"	43.6	39.2	35.3	37.6	30.3	37.2
⅜"	17.8	14.0	16.1	11.7	11.3	14.2
.263"	5.3	3.2	6.1	3.3		4.5
.185"	1.5	.2	1.4	0.7	0.4	0.8
Pan	0	0	0	0	0	0

Concrete. - Concrete of a 1:2:4 mix, proportioned by loose volume was used in the test beams. The materials were measured in buckets of ½ cu. ft. capacity and the weights were recorded as a check. As dry a mixture as could be placed and tamped around the reinforcing bars was used.

The work was done by men from a contractors crew, accustomed to mixing concrete, under the supervision of H. F. Gonnerman who personally checked the amounts of materials on the first 10 or 12 beams. Other work prevented him from exercising any but a general supervision over the making of the remaining beams.

Steel. - The longitudinal steel was furnished by the Illinois Steel Company of Chicago. Three different lengths of bars were used and unfortunately there are indications that the different lengths had different yield-points due probably to having been

TABLE 4.

TENSION TESTS OF STEEL FROM BEAMS.

Beam No.	Yield-Point Stress. lb. sq. in.	Ultimate Strength lb. sq. in.	Per Cent Elongation in 8 in.	Length of [illegible] in feet.xx
393.1	39000	57500	30.0	18 or 30
"	40200	58200	27.5	30
"	42700	62600	30.0	30
"		55800	30.6	30
Av.	40630	58520	29.6	
394.1	39600	55800	30.0	30
"		57200	23.8 x	30
"	38700	57200	28.8	30
"		57300	31.8	30
Av.	39150	56620	30.2	
398.1	39000	60200	28.1	30
"	36600	58800	29.4	30
"	36600	57900	27.5	
"	38800	56500	31.2	—
Av.	37750	58350	29.1	
399.1	38200	63500	27.5	30
"	35600	57700	25.0	30
Av.	36900	60600	26.2	
380.2	38000	61000	28.1	
"	38600	61000	28.1	
"	37000	38200	29.5	
"	40100	58500	30.6	
"	36000	57000	30.	
Av.	37940	59140	29.3	
381.2	37000	58600	30.6	
and	36300	57500	28.7	
397.2	35500	56400	29.4	
"	36700	56000	31.8	30
"	373000	61700	28.8	30
"	35600	57200	30.0	20
"	36600	59000	29.4	30
"	33600	54300	28.1	20
Av.	36080	57590	29.7	
382.2	37800	54600	35.0	20
"	41000	63000		
"	37500	55300	31.2	20
"	38300	54300		18
"	37900	58900	31.2	30
Av.	38500	57220	32.4	

(TABLE 4 Cont'd)

TENSION TESTS OF STEEL FROM BEAMS.

Beam No.	Yield-Point Stress. lb. sq. in.	Ultimate strength lb. sq. in.	Per Cent Elongation in 8 in.	Length of Bar in feet.**
387.2	38700	60000	22.5 *	30
"		57500	28.1	30
"		56700	32.5	30
"	40400	58100	30.0	30
Av.	39500	58080	30.2	
388.2	35000	55200	30.0	20
"	34000	56200	28.7	20
"	37000	59300	27.5	30
"	36700	59000	31.2	30
"	36000	57700	29.4	18
Av.	35740	57480	29.4	
389.2	35800	56900	30.0	30
"	39200	58300	31.2	30
"	37000	56500	30.0	
"		56500	30.0	
"	38800	58300	30.6	30
"		58200	28.8	30
Av.	37700	5 37530	30.1	
390.2	38900	58500	30.6	30
"	40300	58300	30.0	
"	36000	57500	29.4	30
Av.	38430	58000	30.0	
398.2	38000	57000	28.8	30
"	38400	56600	28.1	30
Av.	38200	56800	28.4	

** Probable length of bar from which the coupons were taken.
* Broke outside of punch marks. Not included in Average.

TABLE 4 (CONT'D).

TESTS OF STIRRUP STEEL.

Spec. No.	Stress in lb. per sq. in. at Yield Point.	Ultimate.	Per cent Elongation in 8 in.	Per cent Reduction in Area.
1	77300*	132100*	11.9*	26.2*
2	42900	61600	27.5	42.8
3	45500	61200	26.2	42.2
4	52800	76500	23.8	37.8
5	42900	61500	25.0	41.3**
6	56600	83200	21.9	34.0
7	42200	56200	28.8	39.0
8	37900	53800	28.8	43.5
9	44100	60500	26.9	41.3
10	40700	58500	28.1	42.4
11	58700	83700	21.9	31.7
12	66200*	106300*	13.7*	20.6*
13	43800	59500	28.8	40.1
14	44100	61000	26.2	39.8
15	41200	55500	31.2	48.8
16	39900	54200	30.0	44.7
17	44200	57800	26.9	42.7
Average	45166	62980	26.8	40.8

* Not included in Average.

** Broke outside of gauge length.

rolled from different lots of steel. This was not discovered until many of the beams had been made and consequently the coupons were not marked so it is impossible to state definitely which bars were used in each beam and where more than one length of bar was used in the beam it is likewise impossible to differentiate between them. The 18-ft., bars seem to have a lower yield-point and ultimate strength than either the 20-ft., or 30-ft., and the 20-ft., bars also run a little lower than the 30-ft., bars. The yield-point varied from 33,000 to 40,000 lb., per sq. in. and the ultimate strength from 54,000 to 61,000 lb. per sq. in. The yield-point stress, ultimate strength, elongation in 8 in., and the avaliable data as to the length of the bars from which the coupon were taken, are given in table 4.

6. Specimens. - In the design of these specimens it was sought to avoid some mistakes of earlier designs which had caused failure in some other than the desired manner and which had made impossible the solution of the original problems. High web stresses and, if possible, diagonal tension failures are essential to this solution. To meet this requirement it is necessary to use a deep and comparatively narrow beam, well reinforced against tension failure.

To facilitate comparisons it was decided to use beams of the same general dimensions and subject them to the same loadings as were used by Messrs. Hargis and Gonnerman except that the total depth was decreased from 17½ in. to 17 in. it being considered that 2 in. of concrete beyond the center of the steel was sufficient. The resulting dimensions are 8 in. x 17 in. x 18 ft. 0 in. Since many beams previously tested failed by tension in the steel

or by slipping of the bars due to insufficient anchorage, an increased amount of steel and a more secure method of anchoring the ends of the bars was used. Assuming a steel stress of 35 000 pounds per sq. in., 2 per cent of steel would develop a shearing unit-stress of about 325 lb., per sq. in., even though the actual steel stress is equal to the calculated stress.

It is seldom found in tests that the observed tensile stress exceeds 90 per cent of the calculated stress of 350 lb., per sq. in., should reasonably be expected before tension failure occurs. Shearing strengths greater than 350 lb., per sq. in., seemed quite unlikely from data available and 2 per cent was choosen. Eight $\frac{5}{8}$-in., round bars gave this per cent.

The most feasible method of anchoring the bars was to hook them at the ends. Theoretical considerations as well as tests indicate that a 180-degree hook having a diameter of 6 times the diameter of bar is sufficient to develop the tensile strength of the steel. To facilitate the bending of the bars it was desirable to have the radii of all hooks and bends the same. The necessary diameter of hook from above considerations would be $3\frac{3}{4}$-in., but to reduce the danger of the concrete crushing under the bends it was decided to increase this diameter to 6 in.

To provide against the possibility of a diagonal failure between the support and the end of the beam two vertical stirrups were used in addition to the bars bent down in this region. The location of the steel and all details are given in the drawings of the beams.

7. <u>Auxiliary Specimens</u>. - Two to four concrete cylinders, some 6 x 12-in., and some 8 x 16-in., were made with each beam, that is of concrete from the same lot as that used in the beam.

Usually two 6 x 12-in., and two 8 x 16-in., cylinders were made. Compression tests of these gave the modulus of elasticity and ultimate strength of the concrete used,

8. Fabrication. - To complete the series as outlined it was evident that the fabrication as well as the testing must proceed rapidly and smoothly. One of the first problems to settle was the method of bending the bars. An apparatus or machine was built with which it was possible to bend a bar thru any angle up to 180 degrees with a radius of bend of 2 in., This apparatus could be used for all the bends and hooks and proved very successful. The bars bent in this way conformed closely to the dimensions given.

In the beams having bars bent down at three points a somewhat unique method of bending some of the bars had to be resorted to in order to obtain strain gage readings on both bars at each section at which bars were bent down. The outer bars of each layer were close enough to be read on by bending down in the ordinary manner. For the third section it was necessary to use two of the inner bars which were approximately 2^{3} in., from the side of the beam and could not be reached with the strain gage. These bars were therefore bent out at a small angle until within about $1\frac{1}{2}$ in., of the surface and then down in the usual manner. At the bottom of the beam these bars interfered with the other bars already down and were therefore bent at a small angle across the width of the beam. The drawings will make this clear.

The rods were securely wired into place in the form, being supported at the top of the beam by a small rod running thru the sides of the form. This cross rod was removed as soon as concrete

had been poured to prevent the formation of settlement cracks below the bars, another source of trouble in previous tests.

Instead of chipping holes in the concrete for strain gage readings in the steel as was done in the earlier tests and on similar beams by Hargis and Gonnerman, corks were attached to the forms in the proper positions for gage holes before the concrete was poured. In the first beams the steel was placed first and the corks nailed in place under the bar. Later it was found that the position of the bar could be laid off on the form, the corks nailed in place and the bar wired against the corks with much greater ease. This also furnished a good check on the bending of the bars. The removal of the corks from the concrete made the holes in the concrete at the places where gage holes in the steel were to be drilled. About one-third of these stuck to the forms and consequently were removed from the concrete when the form was removed from the beams. The remainder had to be removed in preparing the beam for test.

The concrete was mixed in a Wonder Mixer in batches of about five cu. ft. An amount of water known to be just a little less than the amount required for the proper consistency was first introduced into the mixer. The gravel and sand were then poured in and finally the cement and remainder of water added. The whole was mixed for four minutes after all ingredients were in the mixer. Four batches were required for each beam and to secure uniform results they were all mixed separately, dumped on the floor and the whole batch turned by hand.

The amount of water used was measured by a glass gage. About 8% gave the desired consistency and was supposedly used thru-

out. This gave a mixture which required considerable tamping to fill in properly around the reinforcing bars near the bottom of the beam and quite naturally did not appear to meet the approval of the workmen. This mental attitude of the men together with the appearance of some of the beams makes it seem probable that the specified amount of water was exceeded in some of the later beams which may account for the greater variation in strengths found in these than was found in the first beams. However the concrete as a whole is much more uniform and of a better quality than has been produced in previous years whether it be due to a better grade of cement, the new mixer or to the use of a smaller amount of water.

Wooden forms of the knock-down type were used. The form was set on a strip of building paper on the floor of the laboratory, the steel was wired in place, and the concrete was placed with shovels and tamped with small bar tampers. Wooden clamps made up of two 2 x 4-in., pieces about 36 in., long separated at the top by a cross piece the length of which was equal to the width of the form, and tied together by a bolt at the center were used to hold the forms together. Due to stress and dampness the 2 x 4-in. pieces warped and allowed the forms to separate somewhat resulting in oversize beams. This difficulty was remedied by using 4-in. channel sections in place of the 2 x 4-in. pieces.

Slight irregularities in the floor resulted in beams of somewhat over 17 in., total depth.

With use, these wooden forms warped somewhat so some of the beams were slightly curved, in one case about 1 in., out of line at the center, and others were twisted. It is hardly thot that this is sufficient to affect the total load carried in any case

but it seemed to cause unequal stress on opposite sides of the beam at the lower loads in beam.

The forms were left on the beams from four to seven days after which the beams were covered with burlap and left in place for about two weeks. They were then stacked two beams deep and covered with wet burlap.

9. Storage. - The beams were stored under burlap and wet down at least twice a day until within from 7 to 10 days before testing at which time the burlap was removed and beams allowed to dry out. Part of the cylinders were stored with the beams and the rest in the damp room. The temperatures of the beams varied from 55 degrees to 75 degrees F., and the temperature in the damp room varied from about 68 degrees to 72 degrees F.

10. Preparation, For Testing. - After the beams had dried out they were first white-washed to make cracks more readily found. All corks which remained in place after removal of the forms were removed, and all the holes were chipped out so as to expose the rod at each point at which a strain gage hole was desired. Gage holes were then drilled in the steel with a No. 54 drill as is generally done for strain-gage readings. This completed the preparation until the observer took charge. However, it was found helpful in obtaining good readings for the observer to go over all the holes and "work them out" with a strain gage before any readings were attempted.

Handling. - At the time of pouring, two stirrups or loops were placed in the beams about 6 ft., from the ends by which the beams could be lifted. An electric hoist was used to move the beams and put them in the testing machine.

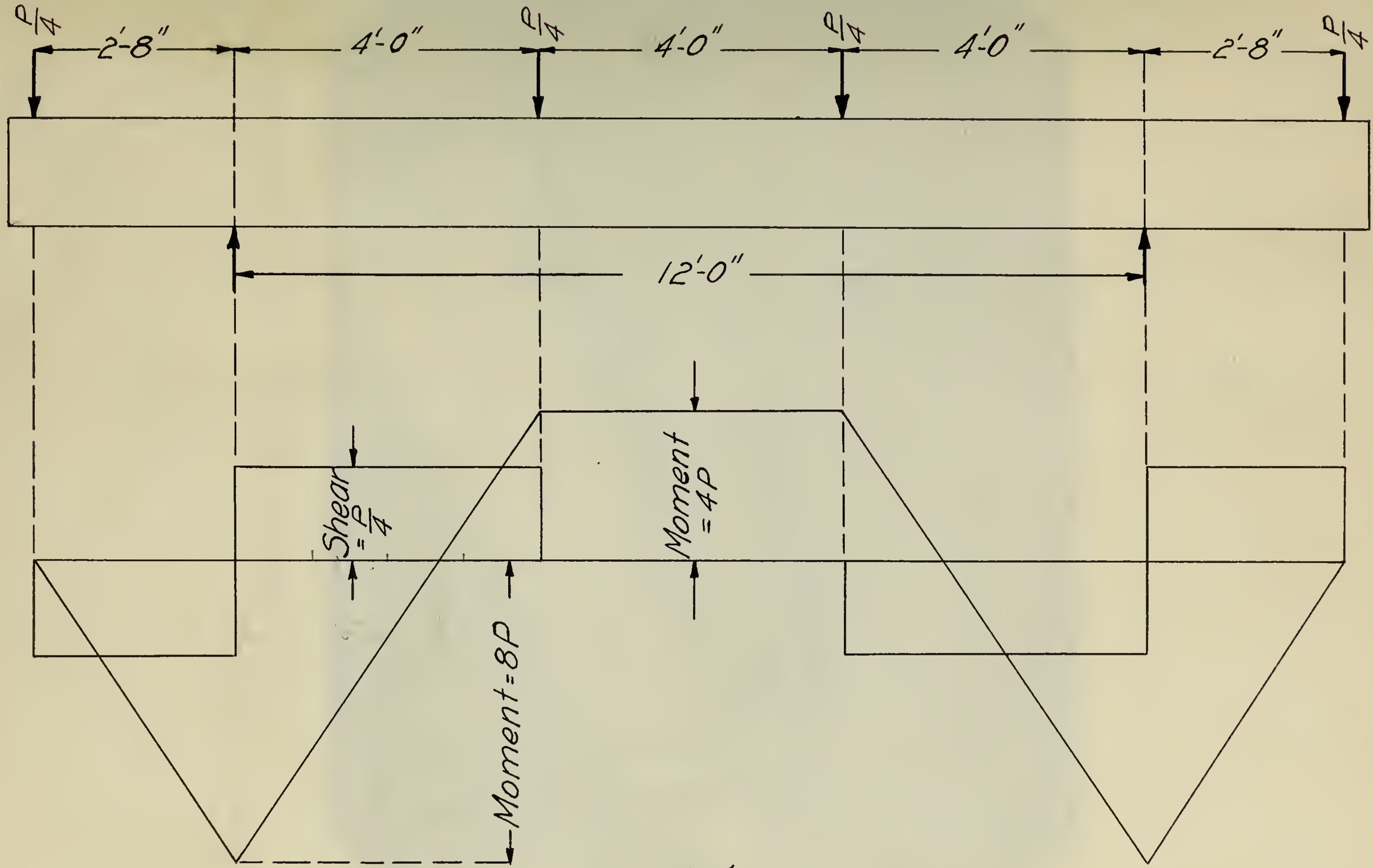


Fig. 1.

Method of Loading Beams and Corresponding Shear and Moment Diagrams

Fig. 2.
View of beam in machine ready for test.

11. <u>Loading</u>. - The beams were loaded at four points with equal loads as shown in Fig. 1. The inner loads were applied at the one-third points of the 12-ft., test span, and the outer loads were applied at points 32-in., from the supports thus producing a ~~movement~~ moment over the support twice that at the center of the span.

The load was transmitted to the concrete beam thru 4 x 8-in., plates. They were set in plaster of paris in most cases in order to distribute the bearing and prevent crushing failure. The concrete beam rested upon 6 x 8-in., plates supported by rollers. The beam generally rested directly upon the plates without embedment in plaster of paris and no crushing was observed due to unequal bearings. The bottom of the beam was naturally smooth so no trouble should be expected in this direction. In one case when the beam was very much out of plumb it was shimmed up with building paper and in another the beam was raised and set plumb in plaster of paris. There were other instances where beams were out of plumb but only slightly so nothing was done to correct it.

A view of the apparatus is shown in Fig. 2. It consists of two 20-in. I-beams resting upon two 12-in. I-beams at each end. The entire apparatus is made integral so as to remain centered, the upper and lower I-beams being held together by stirrups, between I-beams and looped around the large roller shown. The external stirrups kept the lower I-beams in a horizontal position, while the apparatus was being hoisted into and out of position. Thru this arrangement it was possible to hook the electric hoist into the stirrup formed by the $\frac{3}{4}$-in., rod seen projecting above the 20-in., I-beams and to move the apparatus intact thus saving a great deal of time in setting up the specimens.

The load traveled from the head of the machine thru the 4-in., bolt, thru the 1 x 6-in., blocks, seen on top of the 20-in. I-beams to the large I-beams thence to the 12-in., I-beams and finally was applied in four equal parts to the concrete beam. Equal distribution and freedom of end restraint was insured by the use of rollers thruout.

The load was applied at the rate of about 0.3 in., per min., on most beams up to a load of 120 000 lb. ~~per sq. in.~~, after which the slow speed, or about .06 in. per min., was used. The load was generally brought up to the desired reading just once and no effort was made to keep it constant during the time of taking readings. The amounts that the load dropped off during the time of taking the observations is given in the original data. The per unit of drop-off in terms of the load before the yield-point of the longitudinal reinforcement of the beam had been reached was usually so small that it would have had small effect on the readings if load had been kept constant. In some cases there may be inconsistencies in the amount of drop-off due to the sluggishness of the machine. It seems that a sudden failure causing a shock on the machine often disturbs the knife edges and unless these are properly adjusted again it may require as much as 2000 to 3000 lb. to bring the weighing-beam of the testing machine from the bottom to top of gate. On the other hand when machine is in adjustment, the addition of 100 pounds on the table of the machine will raise the beam. This was not known when the first beams were tested and the load readings may not have been quite as accurate as the later ones. While the actual loads on the beams are sufficiently accurate, dependence can not be placed on the amount of drop off shown in some of the first beams tested.

EXPERIMENTAL DATA

AND

DISCUSSION.

EXPERIMENTAL DATA AND DISCUSSION.

General Remarks. - The gage lines common to most of the beams were numbered according to a definite scheme. The beams were divided into sections the first being over the support. All numbers in this section were between 1 and 10. The gage line on the outer, lower bar was No. 1; on upper, outer, bar No. 2 and on upper, inner bar No. 3. Often only No. 2 was read. For the web reinforcement the sections are not vertical and perhaps the term section is a misnomer but each section includes a corresponding portion of each rod. The first digit of the number indicates the position on the bar and the last one indicates on which bar the gage line is located. The 20's are on the horizontal part of the bars, next to the bend at the top of the beam, the 30's are on the inclined portion of the bars adjacent to the top bend, the 40's are near the center of the web, the 50's on the slope, adjacent to the lower bend and the 60's are on horizontal portions near the lower bend. Gage lines at the center of the beam were 81 and 82.

Stirrups were designated by the letters of the alphabet beginning with "A," 8 in. from the support "B," 12 in. and so on for each 4 in. space as far as the inner load point. The upper gage line on a stirrup was numbered "1" and the lower one, "2". The gage lines on opposite sides and ends were similarly numbered and readings at the north and south ends of the beam as tested are distinguished by the letters N and S respectively. The four gage lines on the top of the beams over the support were numbered 3 N and 3 S. All gage lines on the sides of the beams not referred to in the above descriptions of the numbering system may

be found in the photographs of the beams, taken after the tests.

The gage lines on the top of the beam could not be shown by these photographs. Those over the supports have the numbers 3 N and 3S. There was one on each side of the beam at each end. Other gage lines on the top have numbers from 11 to 17 inclusive and a letter (a or b) suffixed. Any gage line on the top of the beam for example 15b, was at the same distance from the support as a gage line on the side having the corresponding number, in this case 15. The data sheets are labeled East and West to avoid any confusion in locating the various gage lines.

The beams were always placed in the testing machine in the same way. The east end of the beam as it was poured was turned south in the machine. This was done in order to detect any consistent difference in strength of the two ends due to some unlooked for peculiarity in the making, curing or testing of the beams should such difference be present. No such peculiarity has been discovered, however.

The readings were taken with a Berry strain gage designed especially to permit reading on reinforcement as much as $1\frac{1}{2}$ in. below the surface of concrete. This instrument is adjustable for gage lengths up to 8 in. In all but the first two beams, however, the gage length was 4 in. and in these it was 6 in. The 4-in. gage length was considered satisfactory to determine the stresses with the necessary accuracy and has the advantage over a greater gage length of giving more nearly the maximum stress in a bar at the desired point.

Zero readings were taken with no load on the beam except the weight of the beam itself. The machine was balanced with the

loading apparatus resting on the head of the machine so the reading on the scale beam gives the actual load including the apparatus. All calculations and curves are based upon the load shown on the scale beam thus neglecting the dead load of the beam. The loads used were planned to give shearing stresses, which were multiples of 50 lb. per sq. in. This greatly reduced the time required for plotting the stress-deformation curves. In choosing the shearing stress at which readings should be taken an attempt was made to reduce the number of readings to a minimum consistent with obtaining results that would completely determine the curves. For this reason only part of the gage lines were read in many cases and some were omitted entirely in the later beams. The last readings were usually taken when the steel reached its yield-point at some gage line or when failure seemed imminent. In addition to the strain gage readings, slip readings were also taken on the straight bars in some of the first beams tested. In certain types of beams these readings showed no slip or showed a negative amount of slip, indicating compression in the bars at these points, so consistently that they were later omitted on such beams.

For the sake of convenience and clearness the reinforcing bars have been numbered as they pass over the south support. The upper layer includes bars 1 to 4. No. 1 being on the east side, and the lower layer includes bars 5 to 8, there also being numbers from the east. The sectional views of the beams show the position of each bar over the support. In the phenomena of tests the bars will be referred to by number.

In speaking of the first bar down the bar bent down nearest the support will be meant and similarly for the others.

The abbreviations S. E. face, N. E. face, S. W. face and N. W. face, will be used meaning south of center, east side; north of center, east side; south of center west side; and north of center west side, respectively.

Phenomena of Tests. - Since the general behavior of all the beams was very similar, only the phenomena peculiar to each specimen will be given for the individual beams.

Tension cracks extending down to and in some cases across the tension rods, to a point about 4 in. from top of beam usually formed at loads from 20 000 to 40 000 lb. There were instances where no tension cracks were visible at 40 000 lb. and others where the cracks extended downward 6 in. at the same load. As the load was increased these cracks extended and new ones formed on both sides of the support as well as directly above it. The tension cracks at the middle of the beam usually did not appear until higher loads were reached probably 80 000 lb. This is to be expected when it is remembered that there was usually 50% more steel in proportion to the bending moment at the center than over the supports.

The photographs of the beams plainly show the progress and character of the cracks.

12. Explanation of Tables. - The heading of each of the tables to 5 inclusive affords explanation.

Table 6 gives the method of reinforcing the beams, the maximum loads, shearing unit-stress at the maximum load and the strength of the concrete cylinders made from the same batch of concrete as the beams. The shearing unit-stress is calculated by the formula, $v = \frac{V}{bjd}$. The compressive strength of the cylinders generally is the average for two cylinders usually one 6 x 12-in. and one 8 x 16-in. cylinder. One of two columns gives the average strength of the cylinders stored with the beam and the other gives the strength of those stored in damp sand.

13. Explanation of Diagrams. - On pages 68 to 119 will be found the Stress-Deformation Curves. These show the relation between the shearing unit-stress on the beam and the unit-deformation in the steel at each gage line for all loads. Deformations which greatly exceed the yield-point deformation are usually not plotted. The unit-deformations are obtained from the strain gage readings by the standard method of reduction used by the Illinois Experiment Station.

The set of curves on pages 120 to 137 show the variation of stress along the bent-down bars. The gage lines are laid off to scale horizontally the distance between them being the average distance between them measured on the bars in the beams. The unit-stresses are obtained from the unit-deformations shown in the Stress-Deformation curves, assuming a modulus of elasticity of 30 000 000 lb. per sq. in. for the steel. The value plotted for any given gage line is the average of the values for this gage line

at both ends and both sides of the beam. Each beam is shown by a different kind of a point. The curve drawn represents the average for the two beams of the same kind for a particular value of the shearing unit-stress. Curves on pages 138 to 142 are Average Shear-tension curves. These are similar to the Stress-Deformation curves except that stress instead of deformation of the steel is plotted, and the values of the stress plotted are the averages of all gage lines similarly located on both beams of the same type. These curves are plotted for gage lines 31, 32, 33, 41, 42 and 43 and only for beams having inclined bars, without stirrups.

Curves showing the effect of angle, of spacing and of distance from support to first bend are given on pages 143 to 146.

The stresses plotted are the averages for both beams. Each of these curves will be explained more in detail in the analysis of data.

The stress-deformation curves for the cylinders for each beam are shown on pages 208 to 210. Extensometer readings were taken on one cylinder for each beam and the results are shown by these curves.

14. Explanation of Photographs and Drawings. - The photographs are self-explanatory. Views of both sides of all the beams and in addition close-up views of some of the beams showing the condition of cracks just before final failure or the condition of the beams after failure are shown. In the full length views of the beams the cracks are all painted. On the close views the cracks are usually only penciled. The end of the crack at each load is marked. The gage line numbers are also painted on the beams.

The drawings pages 184 to 205 give the details of the reinforcing in each beam.

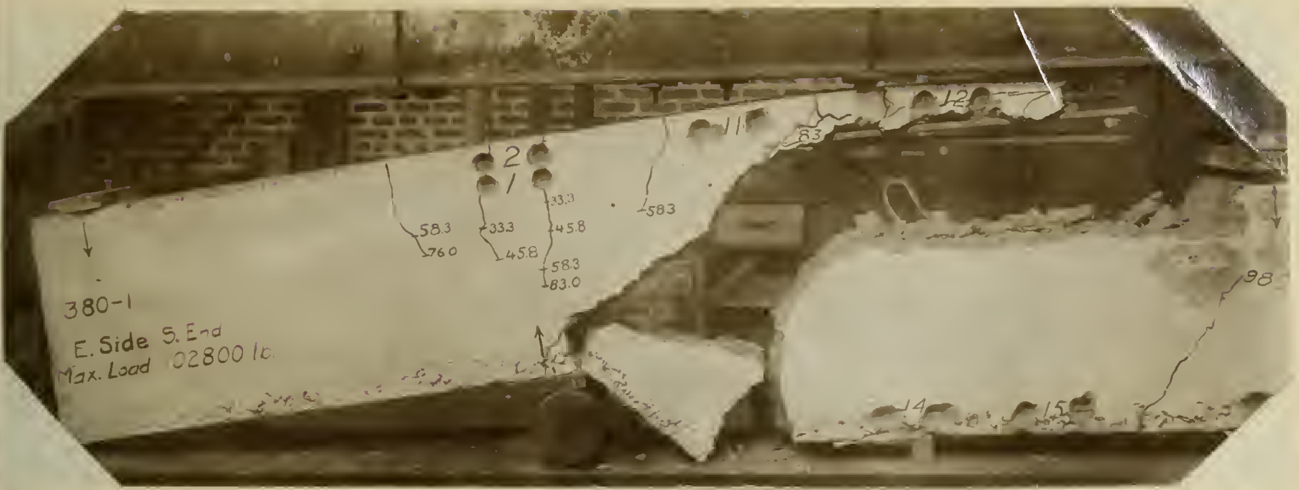
16. Phenomena of Tests.

BEAM 380.1

This was one of the plain beams with no steel crossing the web. There were eight bars over the support hooked in the usual way at their outer ends, but run straight for a distance of 20 diameters past the point of inflection. In the bottom of the beam were 4 straight bars which also extended 20 diameters past the point of contraflexture.

The location of the gage lines on this beam are shown in the photograph, Fig. 3 . In order to detect any slipping of the bars Ames dials were attached to the outer bars of the lower layer of negative reinforcement, bars No. 5 and 8. At the last observations, with load of 95 800 lb. these dials all showed a slight negative slip indicating compression. This is verified by the strain gage readings on gage lines 13 which were at the end of the upper bars at the same point as the dials.

Small tension cracks formed over both supports at 20 800 lb. load and at 33 300 lb. similar cracks were found crossing gage lines 11 at all points except on the S. E. face. Up to a load of 98 000 lb. this beam acted in the same manner as one with web reinforcement but at this load a diagonal tension crack, formed and was apparently opening up suddenly. The load reached 102 800 lb. when the beam failed suddenly at south end. A view of this beam after failure but before removal from the testing machine is shown on page 27 Fig. 4 . It will be noticed that diagonal tension crack extended up to the longitudinal steel and then followed the bars splitting off the concrete above the bars out to the load point. The diagonal cracks running down from the inner load points were also seen to be opening up somewhat at a load of


380-1
E. Side S. End
Max. Load 102800 lb


380-1
E Side
N End
Max Load 102800 Lb

Fig. 3.


380-2

Fig. 4.

98 000 lb. but they never became dangerously large.

BEAM 380.2

This beam was a duplicate of 380.1.

There were some additional gage lines on the steel of this beam but no slip measurements were taken. Readings were also taken of the deformations in the concrete web of this beam near the supports.

Up to a load of 61 380 lb. the behavior of this beam was similar to its mate. At this load, however, a diagonal tension crack formed at the S. E. extending from gage line 11a across "a" and "b," stopping just short of "e". At 81 800 lb. diagonal cracks were visible across "a" toward "c" and "d" on N. E., and across "a", "b", "c", "f", and "e" on S. W. On the S. E. the crack noted at the previous load had extended across gage line "e."

During the application of load up to the maximum of 104 000 lb. nothing new developed. The old cracks extended and increased in size until the beam failed suddenly at south end.

Special care was take to observe any slipping of the bars in the top of the beam but none could be seen before failure. From appearances it seemed that the diagonal crack opened up as far as the horizontal bars and then extended along them toward the load point until finally the whole mass of concrete above the rods split off in which case no slipping of the bars would be necessary to cause failure.

BEAM 381.1

This beam had 6 of the 8 reinforcing bars bent down at practically one point, passing thru the line of inflection at mid-

height of the beam.

The failure of this beam was unique only in the high ultimate ~~loads~~ carried. Diagonal cracks began to appear at about 70 000 lb. load but final failure did not occur until 165 000 lb. when the concrete began to crush under the bend in the bars at the north end of the beam. The load decreased to 140 000 when a set of readings was taken. After taken the readings the load had decreased to 134 300 lb. Failure occured at the north end immediately after taking the last set of readings, without the application of more load, by a rather violent explosion of the concrete under the bends of bars. The condition of the beam after failure is shown in the photograph.

BEAM 381.2

The diagonal tension cracks extending from support toward gage lines 21 and 22 at both ends were first noted after the application of 83 040 lb. load. They were then about .01 in wide. By the time the load had reached 105 500 lb. the diagonal crack at the north end had increased to a width of .03 in. At this load there were also tension cracks across all gage lines 61 and 62. As load was applied the diagonal cracks opened slowly until a load of 120 000 lb. had been reached when the one at the north end began to open rapidly resulting in failure at a load of 124 100 lb.

BEAM 382.1

This was the first of the set of beams made to study the effect of angle of bend on the stresses. There were two bars down 8 in. from support and three more 20 in. out, all at an angle of 22° ~~in.~~

The vertical center lines of the end faces of the beam were about $\frac{3}{8}$ in. out of plumb. Increments of load of 20 400 lb. were used. Up to a load of 81 600 lb. nothing but small tension cracks were visible but about this time several diagonal cracks formed between the support and the point of inflection. The largest of these was about 20 in. out and extended from the top to about the center of the beam. No new cracks of importance appeared until at a load of 142 800 lb. a somewhat flatter diagonal tension crack formed at the north end crossing the center of the web about 27 or 28 in. from the support or about 5 in. from the point of inflection. This crack could not be traced any closer than to within about 4 in. of the edge of beam at the top and bottom. At 163 200 lb. a crack similarly located but extending only about one-third of the distance across the beam from the top, appeared at the south end. The first mentioned diagonal cracks were also opening up and extending. An increase of load up to 166 000 lb. caused tension failure in steel over supports, and the width of the original diagonal tension cracks had increased to about 1/32 in. The load was further increased, at 175 500 lb. another set of readings was taken and at 176 000 lb. the load began to drop off rapidly and beam failed by diagonal tension at the north end.

BEAM 382.2

The usual tension cracks followed by the more inclined cracks were found on this beam. At a load of 83 000 lb. a diagonal crack was visible across gage line 31 on both sides and at both ends, and at 103 000 the same thing was true for gage line 32. At 169 500 many of the cracks had opened up considerably. The tension crack over the N. Support was about .04 in. wide and the

diagonal crack across gage line 22 N. E. was bout .01 in. wide and the one across gage line 31, about .01 in. wide. On the N. W. the largest crack was across gage lines 22 and 31. This was about .01 in. wide. At the south end the cracks across gage line 21 were about the same width but the crack about 8 in. outside of the support on the S. E. was nearly .03 in. wide.

At a load of 175 500 lb. the concrete began to crush under bends of first bar bent down at N. end. The diagonal cracks had changed very little but the the tension cracks had opened up to about 3/16 in. At the S. end cracks at an angle of about 30 deg. with vertical were about ¼ in. wide. Load reahed 183 700 lb. when the crack at about 45 degree angle opened up and beam failed suddenly at north support.

BEAM 383.1

Before any load was applied to this beam, horizontal cracks were noticed below the third bar bent down at north end undoubtedly due to settlement of the concrete in setting.

Up to a load of 166 200 lb. nothing noteworthy happened. At this load the concrete was apparently crushing under the bends of the first two bars at the north end leaving a crack above the bar. The diagonal cracks never became serious and beam failed by tension over support at south end at a load of 183 000 lb.

BEAM 383.2

At a load of 168 000 lb. a diagonal crack crossing between gage lines 21 and 31 at the north end was about .06 in. wide and the first bars bent down had pulled away from concrete slightly

at the bend. At the S. end the corresponding crack was about .01 in. wide and crushing was commencing under the bend of the first bar on east side. At 170 000 lb. the diagonal crack at the south end opened up rapidly and concrete spalled under first bar on west side. At 180 000 lb. the concrete began crushing slightly about 1 in. outside of the north support.

Maximum load was 181 500 lb. This beam finally failed by a diagonal crack opening up at about 45 degrees and starting at north support but the cause of failure can hardly be ascribed to diagonal tension. The concrete under the bends of the bars spalled away so much that they lost their effectiveness in resisting either web stresses or tensile stresses due to the bending moment.

BEAM 384.1

Ames dials were attached to the ends of the straight bars to detect any slip but as usual these dials showed that there was compression instead of tension in these bars. The south dials showed from .007 to .013 in. movement while the north dials showed an average movement of .025 in.

No diagonal tension cracks of any size developed in this beam. Tension cracks starting at top of beam from a point about 6 to 8 in. on either side of center line of support appeared at the usual loads.

At a load of 164 400 lb. scaling of the steel was noted in both supports. The concrete showed evidence of slight crushing under bends of first two sets of bars down at each end. The beam failed at a load of 176 700 lb. by a diagonal crack running up from south support but failure was probably due primarily to the large elongation of tension steel over support.

BEAM 384.2

The readings at 159 400 lb. showed that the steel was past the elastic limit at gage lines 21. The diagonal tension cracks were all small, the largest crossing gage lines 22 and 41. At 169 600 lb. the diagonal cracks were still small but tension cracks over north support were about ⅛ in. wide. At 171 200 lb. the diagonal crack on S. W. face was about .01 in. wide and a large tension crack had formed outside the north support. The load was increased to 174 400 lb. when concrete crushed under bend of first bar on N. E. face. Load dropped to 170 000 lb. but soon increased again to 178 600 lb. when spalling occured under the first bend on N. W. face. Load again dropped off about 26 000 lb. With continued application of load, the load decreased to 172 000 lb. when the concrete spalled under second bar on N. E. face.

At the time the beam reached its maximum load readings were taken on gage lines 41, south, end. The east side showed a deformation from two to three times the elongation at the yield point of the steel.

Hence it is apparent that though the beam actually failed by a crushing of the concrete under the bends, the web stresses were really very high.

BEAM 385.1

Slight settlement cracks noted under the bends of the second bar down (bar 4) on the west side at both ends of beam.

The steep diagonal crack crossing gage line 21 was about 4 in. long at S. end and about 10 in. long at N. end at a load of 62 600 lb. At 83 500 lb. a diagonal crack crossed gage line 22 and the lower end of 31 both ends making an angle of about 45 de-

grees with the vertical. The cracks across gage line 21 N and S began to open up at 125 300 lb. expedially at the north end. At 146 200 lb. a short crack formed across 42 S. at the point of inflection. Another crack formed very close to this at the S. end and a similarly located one at the N. end at 165 000 lb. At this load the tension cracks over the supports opened wide and the widest diagonal crack was about .02 in. The bars were just beginning to pull away from the concrete at the bends at the N. end of the beam and the Ames dial showed a slight slip of the straight bar near inner load point. At the S. end also there was a slight crushing under the bends of the bars but the dials readings showed negative slip indicating compression in the bar at this point. From this point the beam took load slowly up to 176 300 lb. which was the maximum load applied.

BEAM 385.2

At north end inclined cracks crossed both gage lines 21 and 31, at load of 62 700 lb. but at south end there was only one crack and that crossed only 21. At a load of 164 000 lb. a crack appeared near each of the inner load points and at 168 000 lb. this crack had extended down to gage line 51 at each end. These cracks over the supports and the steepest diagonal cracks at each end were about .02 or .03 in. wide. As the load was applied the tension cracks at both supports opened up. Later a tension crack opened up at gage line 61 N. and soon another at the center of the beam. As this tension crack at the center extended it branched out into two parts. The load carried by the beam increased up to a maximum of 190 000 lb. when the concrete failed in compression about 20 in. N. of the center of the beam.

BEAM 386.1

Slight settlement cracks were noted under bar 1 near gage line 22 at S. end and under bend of bar 2 at N. end. Action at both ends was very similar for lower loads. An inclined crack crossed gage line 21 at both ends at 61 800 lb. load another crossed 22 and 31 at 62 400 lb. and at a load of 123 600 lb. a crack extended from the top of the beam at gage line 23 downward toward the support at an angle of about 45 degrees. At 164 800 lb. a crack extended from the rods at gage line 53 toward the inner load point at N. end. At the S. end a similar crack formed at 174 000 lb. The diagonal crack crossing gage line 21 was bout .02 in. wide at S. end and about .05 in. wide at the N. end of the beam. These cracks continued opening up and were about $\frac{1}{3}$ in. wide at 187 000 lb. when the concrete spalled out under first bend at S. W. Spalling dollowed on the S. E. at 188 200 lb. the maximum load carried.

BEAM 386.2

As usual the first inclined crack crossed the horizontal reinforcement about 8 in. from the support at a load of 62 200 lb. other cracks formed at flatter angles as the load was increased. At 124 400 lb. a crack was noted extending from gage line 52 toward the load point. At a load of 167 200 lb. the crack across 22 S. was about .03 in. wide. All the cracks were still small at N. end altho the steel had passed yield-point at gage lines 21 and 22. As the load was further increased the diagonal cracks opened up across gage lines 22 S. and 21 N. At 188 000 lb. the concrete crushed under the first bend, bars 5 and 8, at S. end and load fell off.

BEAM 387.1

Slight settlement cracks under bends at south end.

In addition to the steeper diagonal crack crossing gage lines 21 or 31 which were noted at a load of about 63 900 lb. a crack also formed across 21 and between 31 and 41 N. extending to within 6 in. of the support on the N. E. face. At 165 000 lb. the tension cracks over the N. support opened up and the diagonal crack starting at gage line 22 N. was fairly large between inclined bars. At the south end the cracks were smaller but a new crack crossed gage line 52 at this load. Crushing under bends near gage lines 31 S. E. and 21 and 22 on both sides at N. end occurred at a load of 176 000 lb. At 182 000 lb. diagonal crack formed from load point across gage lines 42 and 51 N. W. With further application of the load the concrete spalled first under the bend of the second bar bent down outside of support on the N. W. and later under the bends inside of the support. The load carried by the beam fell off somewhat and a very flat diagonal crack formed running up from the support at an angle of perhaps 20 degrees. with the horizontal. A maximum load of 182 300 lb. was carried but the load at failure was only 180 100 lb. Failure was a sudden by the opening up of the crack crossing gage line 31 at north end.

BEAM 387.2

The 45 deg. cracks crossing gage line 22 were noted at either the 62 640 lb. or the 85 520 lb. load. At 125 280 lb. a crack was found crossing gage line 42 S. and stopping short of the edge of the beam by nearly one-third the depth of the beam at each end of the crack. At 157 700 lb. the diagonal cracks began to open

up on all sides except the N. W. Failure occured at 168 400 lb. by a gradual opening up of the diagonal crack across gage line 31 south end.

BEAM 388.1

This beam did not form a part of any of the three principal sets of beams but was one of the extra types having 4 bars down at an angle of 32½ deg., 14 in. from the support.

The first diagonal cracks appeared at 62 800 lb. crossing gage lines 21 inclined, at an angle of about 45 deg. At 83 700 lb. short cracks formed at a somewhat flatter angle. At 125 500 a diagonal crack was found crossing gage line 41 N. and 41 and 12 S. The largest diagonal crack at 167 300 lb. was about .08 in. wide on N. E. The one on opposite side of the beam was about .03 in. The tension crack across gage line 71 had opened up to about 0.1 in. in width by the time the load had reached 172 000 lb. Bar No. 4 N. end slipped at gage line No. 13 at 173 800 lb. and soon afterward all the straight bars at N. end had slipped considerably. They slipped about 1 in. before load was finally released. Load dropped to 166 000 lb. after the bars slipped and the concrete crushed under the bends of bars finally spalling badly.

Maximum load carried was 173 800 lb.

BEAM 388.2

The S. end of this beam was about ⅜ in. out of plumb.

A diagonal crack, at about 45 deg. extended from the top of beam to gage line 41 on the N. W. at a load of 83 500 lb. At a load of 104 400 lb. similar cracks formed at the S. end, and on the E. side N. end a diagonal crack crossed gage line 31 extending

to within about 5 in. of the bottom and 1 in. of the top of the beam. By this time the load had reached 128 000 lb. the crack across 41 S. E. was .03 in. wide and the one across 21 was about .01 in. wide. On other side of beam the cracks were about the same except the crack across 41 was narrower, probably about .02 in. At N. end cracks were still fine. Straight bars showed evidence of slip at S. end. Load increased to 143 200 lb. when diagonal crack at S. end began to open up rapidly due to steel failure at gage line 41. Failure seemed to proceed from the slipping of the straight bars at gage line 13 to the steel failures at gage line 41, then the diagonal crack opened up considerably and concrete began to split off above straight bars and finally the concrete seemed about to crush under-bends. Failure was gradual and the maximum load carried was 143 200 lb.

BEAM 389.1

The beam of the 389 group were the same as those of the 388 group were with the addition of 4 stirrups between the support and the inner load point at each end. Cracks across gage lines 21 and making an angle of about 45 deg. with the vertical appeared at 61 800 lb. Cracks at about angle or a little flatter crossed gage lines 31 N. E. and 31 S. W. at 82 400 lb. and at 123 600 lb. diagonal cracks extended from the top of the beam across 41. N. W. and 31 S. E. to a point about three-fourth the depth of the beam from the top. A load of 170 500 lb. was applied and a set of readings taken. After which the load was again applied. Tension cracks formed over S. support opened up to a width of about 1 in., then the crack crossing gage lines 12 and 41 at the north end widened to about 3/16 in. As this crack began to increase in width

the load fell off slowly and was about 146 000 lb. when sudden failure occured by the further opening of this crack and the splitting off of the concrete above the straight rods between the crack and the load point.

The maximum load reached was 174 000 lb.

BEAM 389.2

At 61 200 lb. there were fine cracks along the two stirrups near the support and the 81 600 lb. load only increased the number and size of these. At 102 000 lb. diagonal cracks began to appear on the N. E. and S. E. Similar cracks formed on the other side of beam at loads from 122 400 lb. to 161 000 lb. These cracks made an angle of approximately 45 deg. with the vertical and crossed either gage line 31 or 41 or between them. At 1´6 000 lb. a tension crack opened up near the center of the beam. At the load the diagonal crack crossing 21 S. was about .05 in. wide and the tension cracks over the supports were about $\frac{1}{8}$ in. in width. The tension failure at the center of the beam caused a crushing of the concrete at the center and failure at 169 000 lb.

BEAM 390.1

This beam and its mate were the only two in which the bars were the same, being bent down. Two bars were bent down at each of four points with a spacing of 8 in. between bends.

Settlement cracks were under bar at gage lines 23 S. and 24 N. before loading.

Diagonal cracks began forming on the 45 deg. line from the support at about 80 ?00 lb. and extended nearly to the center of the web. The diagonal crack across gage line 21 S. E. was about $\frac{1}{8}$ in. wide at 170 000 lb. and the one across 31 N. E. was about

1/32 in. wide. Concrete was crushing under bar at gage lines 21 and 31 S. E. As load was increased the diagonal cracks near the support opened up, the concrete began to crush first under the bars bent down nearest the support and then under the next one and so on. Later the concrete spalled under the first and third bars S. E. and load fell off. After the maximum load, 181 800 lb. had been reached on low speed the next higher speed of the machine was used. The ~~bad~~ load again reached 180 000 lb. when the S. end of beam split vertically, along the length of the beam. The close view photographs of this beam before and after removing the portion of concrete which split off show what happened.

BEAM 390.2

On the E. side of the beam there were inclined cracks crossing gage lines 22 and 32 at a load of 60 700 lb. At 81 000 lb. a crack had crossed 41 N. W. and at 121 400 lb. concrete had cracked across 42 S. E. The tension crack over the N. support was about .04 in. in width at 163 500. Steel stress had not passed the yield-point at S. support. The diagonal cracks to gage line 22 N. E. were about .01 in. wide at this time and the opposite side was similar. At the S. end the crack crossing gage line 31 was about .01 in. wide. Concrete crushed slightly under bend on bars No. 5 and 8 leaving a crack above bar at this point. At 176 000 lb. a tension crack opened up over S. support. The one at N. support was about 3/16 in. wide by this time. Soon after this the diagonal crack across 22 S. E. opened up and at 180 500 lb. excessive crushing and spalling of concrete took place under bar No. 8 S. support. At 186 000 lb. the concrete crushed and spalled somewhat under bar at gage line 22 N. E. Due to this spalling

the load dropped to 170 000 lb. and remained constant. Just as machine was stopped the S. end of the beam outside of the support failed with a loud report, leaving beam badly shattered as shown in the photograph.

BEAM 391.1

Cracks crossing gage lines 21 and running toward the support appeared at loads varying from 42 400 lb. to 63 600 lb. and began to open up considerably at 127 400 lb. A crack crossing gage lines 23, 32 and between 31 and 41 was noted at 127 400 lb. on both sides at the S. end and on the E. side at the N. end. On the N. E. another crack formed parallel to this and about 6 in. closer to the center of the beam. These latter never reached the top of the beam. At 163 400 lb. diagonal cracks formed extending from the inner load points toward the support an angle of about 45 deg. These cracks started from 2 in. to 4 in. from the top of the beam and extended across all the bent down bars to a point within 4 in. to 6 in. from the bottom of the beam. It will be noted that these cracks pass very close to the theoretical point of inflection. At a load of 167 500 lb. there were indications that steel was slipping thru the concrete at gage lines 21 N. and 22 N. and gage line 21 S. The crack across 21 N. and 22 N. was about .05 in. wide and the corresponding crack at the S. end was about .03 in. The other diagonal cracks were still small at 178 000 lb. the concrete appeared to be crushing under bars 4 and 1, the second bars down. By the time a load of 184 000 lb. had been reached the tension crack over N. support was about $\frac{1}{4}$ in. wide and about $\frac{1}{8}$ in. wide over S. support. The diagonal cracks across gage lines 21 were about $\frac{1}{8}$ in wide. A strain gage reading on gage line 31 N. E.

at this time indicated a stress of 40 000 lb. per sq. in unless the yield point of the steel had been exceeded. The load was increased to 186 800 lb. when a diagonal crack outside of S. support opened up and the concrete spalled under the bends near the end of the beam. Load dropped off and machine was stopped.

BEAM 391.2

At S. end a crack crossed gage line 21 at 40 900 lb. load. Diagonal cracks crossing gage lines 21, 22, 23, 31 and 32 at N. end formed at 61 300 lb. At 81 300 and 102 200 lb. additional short diagonal cracks were noted midway between the support and inner load point. The load was increased up to 164 400 lb. when the diagonal cracks crossing gage lines 21 were opening rapidly. A set of readings was taken here and loading continued until the maximum load 172 000 lb. was reached.

BEAM 392.1

At 62 300 lb. inclined cracks crossed the horizontal steel near gage lines 21. At 83 000 and 124 500 lb. short diagonal cracks formed near the center of the web about midway between support and inner load point. The diagonal crack across gage line 21 was about .05 in. wide at the latter load. At gage lines 22 and 21 the bar was pulling away from the concrete leaving a crack on the lower side at 22 and upper side at 21 apparently due to shear. The load was applied at second speed (as was usually done up to a load of about 160 000 lb. on beams having web reinforcement) and beam failed at 146 600 lb. Up to this point there had been no serious tension cracks or any crushing of the concrete under the bends.

BEAM 392.2

At the S. end the main diagonal crack formed crossed gage lines 21 and 22 and extended to the inner edge of the support. At a load of 61 600 lb. it had reached about to the center of the web and extended slowly for each increment of load from then on. No other diagonal cracks of any importance formed at this end. A similar crack formed at the N. end of the beam but in addition there were several other diagonal cracks. At 123 300, there was one extending from gage line 43 downward toward support at an angle of about 45 degrees. This stopped about 4 in. from the bottom of the beam. Another crack somewhat steeper than this started near the load point at this same load and extended to gage line 51. The crack across gage line 21 N. E. was about .02 in. wide just below the rod at this load and narrower at both ends. On the S. end the corresponding crack was about .01 in. wide being slightly wider on the W. side. Here again the crack was widest just below the bars. At 175 300 lb. the diagonal crack N. E. was about 3/16 in. wide. Concrete spalled slightly under bend on bar 8 N. W. Load reached 176 400 when beam failed by diagonal tension. Either both ends failed simultaneously or the shock of the failure at N. end caused the crack to open up at the S. end. The failure at the south end however was not so complete as at the north end.

BEAM 393.1

Settlement crack was noted under bar 2 S. E.

No diagonal cracks appeared at 41 400 lb. load but some small ones were noted across gage lines 21 at a load of 62 040 lb. At 82 700 lb. cracks were noted crossing gage line 31 and also crossing

32 extending to 41. At 124 080 lb. a diagonal crack extended from the gage line 33 N. E. to 51 N. E. A large diagonal crack extended from the load point down to gage line 62 at the 124 080-lb. load. Increasing the load up to 164 000 lb. the crack across 21 N. opened up and concrete crushed under first and second bends. The load dropped to 148 500 lb. and never reached 164 000 lb. again altho the machine was run for some time.

BEAM 393.2

No cracks at any considerable angle with the vertical formed until at a load of 62 200 lb. cracks were noted crossing gage lines 32 at both N. and S. ends. At 83 000 lb. another crack paralleled the above mentioned one at N. end crossing gage line 42. At S. end a crack about 5 in. long was discovered about 6 in. S. of load point near the center of web of beam. This crack extended to the bottom of the beam when the next load, 124 400 lb. was applied. Also at this load a crack crossed gage line 53 N. extending across the middle third of the web. Load increased up to 170 000 lb. when the crack crossing bar 5 between gage lines 21 N. and 31 N. had increased to about .04 in. in width and concrete was just beginning to spall under the bend of the same bar. At this time the crack across gage lines 53 N. and 62 N. was about .03 in. wide. At S. end the crack from load point to the N. end of gage line 62 was about .01 to .02 in. wide. While taking readings at this load the beam failed, by diagonal tension thru gage line 51 N. Maximum load carried was 170 000 lb.

BEAM 394.1

At 63 100 lb. short diagonal tension cracks appeared under

each of the three points of bending down the bars at N. E. The appearance of the beam was quite similar at the other corners. At a load of 84 100 lb. a crack crossed all three bars near the point of inflection. This crack later extended nearly to the top of the beam. At 161 000 lb. the crack from first bend N. E. was about .06 in. wide and then was a small crack under the bar at gage line 22. This crack was only about one-half as wide on the west side of the beam as on the east. The south end of the beam was about the same as the north end but the crack across gage line 21 was about .06 in. wide on both sides. When the load reached 174 300 lb. the tension crack at S. support opened up to about ⅛ in. and concrete crushed under first bend on the N. W. With a further application of the load, the concrete spalled badly under the bends at N. end of beam.

The close-view photograph of this beam shows the condition of the north end east side before tension failure occured.

BEAM 394.2

A load of 60 700 lb. caused cracks across gage line 21 extending about one-half way across the web at both ends of the beam. A crack extending from gage line 23 across the bars at an angle of about 45 deg. appeared at the south end of the beam at a load of 121 400 lb. and at the north end at 163 000 lb. At the latter load the crack crossing gage lines 21 and 22 S. was about .08 in. wide but the corresponding crack on the N. end was still fine. A crack opened up about 8 in. outside of the S. support at a load at a load of 173 000 lb. on this load the concrete crushed under the bends on bar 5 at N. E. and S. E. at a load of 175 000 lb.

No crushing on the west side at this load. The load increased very slowly, in fact it remained nearly constant for some time and then it picked up quite rapidly to 180 000 lb. A maximum load of 185 400 lb. was reached when concrete spalled badly under the bends at the south end.

BEAM 395.1

This beam was considerably warped. The N. end was also out of plumb, the top of beam being about $\frac{1}{2}$ in. W. of the bottom.

A load of 62 400 lb. caused cracks across gage lines 21 all around and also across gage line 22 S. W. During the application of the next increment of load, at a load of about 82 000 lb, the diagonal crack inside of S. support opened up rapidly and by the time the load had reached 83 200 lb. the crack extended to within about 5 in. of the bottom of the beam. The corresponding crack at the N. end was just about as long but finer. At 124 800 lb. these cracks were both about .02 in. wide. At 150 000 lb. the one at S. end was .05 in. and at N. end .03 in. At N. end bars 5 and 8 had pulled away from the concrete slightly, at S. end bars 5 and 8 had pulled away slightly, they being about .05 in. and bars 1 and 4 had also pulled away slightly. Load increased up to 165 000 lb. and then dropped to 163 800 lb., probably due to crushing of concrete under bends at S. end. Photograph shows condition of E. side S. end of beam at this stage. The cracks on the west were about the same but the crushing under the bends was less pronounced. At the N. end the diagonal crack was still fine. With further application of the load the concrete spalled under the first two bends at the S. and the diagonal crack opened up to perhaps 3/16 in. in width. The load carried by the beam

continued to increase up to 180 600 lb. when sudden failure occurred. The diagonal crack at N. end was about $\frac{1}{4}$ in. wide at the time of failure.

An interesting fact, brought out in this test, as may be seen by a glance at the photograph, is the absence of diagonal cracks crossing the web reinforcement.

BEAM 395.2

At 61 400 lb. a diagonal crack at S. end extended half way across the web crossing gage line 22. At N. end a similar crack extended to within about 4 in. of the bottom of the beam. These cracks were much more distinct on the E. side of the beam than on the W. side. They kept widening gradually as load was applied and at 140 200 lb. the beam seemed to be near failure, the cracks on both sides of beam being about .02 in. in width. At 160 000 lb. the cracks at N. end were about .04 in. wide at center of web and narrower at both end, at S. end the crack extended full width to the top of beam. The concrete spalled under the first two bends at 167 000 lb. and beam failed quite rapidly but not with violence. The absence of diagonal cracks across the bent down bars is to be noted for this beam also as in the case of its mate.

BEAM 396.1

This beam had 6 bars down at the point of inflection and stirrup spaced 8 in. beginning 8 in. from the support. Diagonal cracks began forming at 61 900 lb. load crossing the center of the web about 16 in. from the support. Vertical cracks along the first and second stirrups were also noted at this load. The steep cracks above the support opened up considerably at 123 600

lb. and at a load of 164 800 lb. the steel over S. support had passed the yield point. Short diagonal cracks from the inner load points formed at loads varying from 123 600 lb. to 144 200 lb. With an increase of load the tension cracks were opened up over the supports and concrete spalled slightly under some of the bends. Maximum load carried was 182 600 lb.

396.2

Due to some mistake this beam was not built as designed. Instead of bending all 6 of the bars down thru the point of inflection two of the bars from the upper layer were bent down 10 in. further from the support. A diagonal tension crack appeared at the N. end at 61 700 lb. and at the S. end at 82 300 lb. Other than these the cracks were nearly vertical many of them forming along the stirrups. The yield-point of the steel was passed at a load of 165 000 lb. but before a set of readings could be taken the beam failed very suddenly. Failure came unexpectedly and in a very unusual manner. The concrete outside of the ends of the bars at N. end sheared off. From the violence with which the roller and plates were thrown against the north wall of the laboratory it might seem that the roller slipped out and that the failure was due to the impact of the apparatus on the end of the beam. However this does not seem likely since it never occured during any other test and in many cases the end of the beam was bent down at a much greater angle than this one.

BEAM 397.1

The more nearly vertical cracks formed at about the same loads in this beam as was usual for the beams having bent down bars

for web reinforcement. Some of the more inclined cracks formed along the stirrups for some distance. At a load of 120 000 lb. a crack was noted running from a point at the top of the beam about 20 in. from the support to the edge of the N. support. At the 170 000-lb. load the diagonal crack extending from the support to the first stirrup at the top of the beam was about .07 in. wide corresponding crack at N. support was only about .02 in. wide. The steel apparently passed the yield-point at a load of 168 000 lb. since the beam took load much more slowly after this load was reached. As the load was increased the crack across the top of the first stirrup from the S. support opened up to a width of about $\frac{1}{8}$ in. The tension crack over the N. support opened up to about $\frac{1}{4}$ in. and two tension cracks also opened up to a width of .05 in. or more. At 192 500 lb. the concrete crushed and bulged out under bends at S. end of beam and load fell off. This was the highest load carried by any beam.

The slip dials on this beam showed no movement at all.

BEAM 397.2

This beam was cracked and also out of plumb. The center of the beam was about $\frac{3}{4}$ in. east of a line joining the ends. Paper shims were used to plumb up the beam.

The first diagonal crack to cross a stirrup formed at 82 200 lb. and crossed gage line B2 at both ends. A steep crack which branched off across gage line B 1 also appeared at the N. end at this load. At 123 300 lb. load diagonal cracks crossed the stirrup J and extended toward the inner load point at all four faces. The beam took load uniformly up to 164 400 lb. when load dropped to 157 700 lb. due probably to the opening up of a tension

crack over S. support which took place at this time. The diagonal crack to the top of stirrup D was about .01 in. wide on E. side and .02 in. wide at W. side at this load. The corresponding cracks at the N. end of beam were still fine but the diagonal crack within about 8 in. of the support was from .01 to .02 in. in width. With the application of load the tension crack over S. support opened up. It was about $\frac{1}{8}$ in. at 169 000 lb., and slight crushing occured near the supports on the west side at a load of 175 000 lb. This was probably due to uneven bearing caused by the paper shims used. However it is hardly thot the crushing which occured was sufficient to affect the load carried. Readings on stirrup E, S. W. showed that at gage line E1 the steel was beyond the yield-point at a load of 172 000 lb. After failure it was found that the sliped portion was off about $\frac{1}{2}$ in. Maximum load came at 179 600 lb. when the concrete spalled under the bends of the bars about 24 in. S. of N. support. It is not thot that the straight bars at N. end sliped before the maximum load had been reached.

BEAM 398.1

The load was not applied to this beam at the same rate as in most cases due to the fact that the power was off and load had to be applied by hand after a load of 42 200 lb.

Settlement cracks were noted under bar 1 at gage line 22.

Only one important diagonal crack developed at each end. At the S. end this crack extended across the horizontal steel to the final stirrup, C at a load of 63 300 lb. and to within 5 in. of the bottom of the beam at a load of 84 400 lb. At the N. end it crossed the stirrup C at 63 300 lb. and extended to within about 2 in. of the bottom of the beam at 84 400 lb. load. At

At 126 600 lb. load this crack was from .01 to .03 in. wide on the different faces of the beam. The load increased up to 168 000 lb. when the diagonal crack at the N. end opened up suddenly and load dropped to 114 000 lb. The stirrup crossing this crack held the parts of the beam together. Maximum load was 168 000 lb.

BEAM 398.2

This beam was badly out of plumb, its top leaning toward the east, and was set in plaster of paris to remedy this fault.

One large principal diagonal crack at each end which formed near the top of the second stirrup from the support and crossed the first stirrup at the top of gage line C 2 at a load of 82 400 lb. This crack extended to within about 5 in. of the bottom of the beam at the N. end and to within about 3 in. of the bottom at the S. end. The strain gage readings indicated a deformation beyond the yield-point for the steel at gage line C1 on the west side north end. At 159 700 lb. the steel over support passed the yield-point and the tension crack at this point began to open up. This continued with practically no other change in the beam until a load of 173 100 lb. was reached when the N. end of beam failed by diagonal tensionin crack described above. No large tension or diagonal cracks formed at the S. end of the beam.

BEAM 399.1

The top of beam at S. end was about .4 in. out of plumb toward the east.

Diagonal cracks crossed all gage lines 21 by the time a load of 83 300 lb. had been applied. At 124 900 lb. these cracks were about .01 in. wide. Other diagonal cracks somewhat further out

were finer at 160 100 lb. new diagonal crack crossed the web between the point of inflection and a point midway from the suprort and the load point appeared at the N. end. This was visible to within a very short distance of the top of the beam and within about 5 in. of the bottom. The concrete showed slight crushing under the first bend at N. end E. side and the diagonal crack crossing gage line 31 was about .05 in. wide. At 171 000 lb. the concrete crushed and diagonal crack was opening up rapidly. The tension crack over N. support was about .01 in. wide and the diagonal crack at S. end of beam was about .12 in. wide. There were no indications of tension failure or crushing of the concrete under bends at S. support. The maximum load reached was 176 100 lb. when concrete spalled under the bends on N. E. end and the N. end failed suddenly by diagonal tension.

BEAM 399.2

The steeper diagonal cracks crossing gage lines 21 appeared at 61 700 lb. and at S. end this crack had passed the center of the web at this load. Another crack crossing gage line 52 N. and running toward the inner load point was also noted at this time. At 123 400 lb. a short crack extending between gage lines 42 and 51 N. appeared on the E. side. At this load the width of the cracks about .03 in. indicated that the steel had passed the yield-point at gage line 21 and the second bars bent down had pulled away from the concrete all around. The concrete began spalling under bar 5 N. E. and the diagonal crack at N. end was about 3/16 in. wide. Load reached 184 900 lb. when concrete spalled under first bend N. E. and load dropped off.

BEAM 400.1

This beam had only four bars down at an angle of 22 degrees. The steeper diagonal cracks formed at the lower loads and a crack across the lower end of gage line, making an angle of about 45 deg. with the vertical appeared at the S. end at a load of 82 880 lb. and at the N. end at 124 300 lb. At the latter load a flatter crack formed extending from the top of the beam at the line of inflection across gage line 41 on all faces of the beam. The machine was run at low speed from the time the load reached 120 300 lb. The diagonal crack crossing gage line 41 began to open up rapidly as the maximum load was reached and before machine could be stopped to take a set of readings the beam failed at a load of 151 000 lb.

BEAM 400.2

No important diagonal cracks appeared until a load of 123 080 lb. was applied when a crack crossed gage line 41 at the north end. This crack extended to within 3 in. of the bottom of the beam and was extremely fine at the top of the beam in fact it could hardly be traced to the top on the east side. The 6 in. of the crack just above the inclined bar was the widest portion and at this point it was wider than any other crack on the beam. At a load of 144 400 lb. this crack seemed to be opening up rapidly and a set of readings was taken. The stress at gage line 41 N. E. was found to be 37 000 lb. After the set of observations had been finished another reading was taken on this same gage line and it was found to show an increase of eight strain gage divisions which would correspong to 12 000 lb. stress if steel had not pass-

ed the yield-point. Considering the stress previously found in this bar it is evident that the steel was beyond the yield-point at this time. The beam took load gradually until sudden failure occured at N. end at a load of 149 700 lb.

16. Analysis of Data. - By the load on a beam is meant the load carried by it at the beginning of a set of observations.

The breadth and depth of beam were measured at both ends and the average was used in the computations. A value of .82 was used for j in all calculations. This may be rather low for concrete of as high a compressive strength as was found in these tests but the load increments were all based on this assumption and it was thought best to make the calculations on this basis.

The curves of the individual gage lines pages 68 to 119 show the relation between the unit-shears on the beam and the stress at any particular gage line. By plotting from the same origin the curves for similar gage lines on opposite sides of beam a comparison of the action on opposite sides of the beam is facilitated. In general these curves correspond very closely up to the yield-point of the steel and in many cases the curves are coincident thruout. Opposite ends of the beam also took stress at nearly the same rate but of course there is more difference between the action at the two ends than at opposite sides of the same end.

Curves on page 120 to 137 show the variation of stress along the bars and incidentally also the variation between the stresses in the two similar beams at the same unit-shear. The value plotted is the average of the values for the four gage lines similarly located on a beam. The first and second beams are repre-

sented by two different kinds of points but only the average line is drawn in each case. The curves are plotted for stresses caused by unit shears of 200 lb., 300 lb., and 400 lb. where this was possible. If the deformation at one or more of the gage lines to be averaged indicated that the stress in the steel at this point had passed the yield-point stress the average value was omitted. In many of the beams this was the case for the horizontal positions of the bars just before bending down at (i. e. gage lines 21, 22, 23, and 31, 32, 33) for a unit-shear of 400 lb. per sq. in. For all beams and at all shearing stresses the maximum deformation is shown for gage lines 21, 22, and 23, with more or less of a decrease for 31, 32 and 33. The amount of this decrease varies for the different beams and also for the different bars in beam. As a rule there is more difference in the stress at these two points in the second and third bars down than in the first one in the same beam. On the same bar the difference is usually greater at the higher unit-shears due probably to the larger number of cracks likely to form across gage lines 21, 22 and 23 (that is near the top of the beam) and to the greater proportional effect of the bending moment. In passing along a bar from the upper gage line (30) toward the bottom of the beam the stress decreases in some cases until the horizontal position of the bar at the bottom of the beam is reached but in some cases the decrease does not continue beyond gage lines 40 near the center of the web. This difference is to be expected when it is considered that some of the bars reached to the bottom of the beam in the zone of compression and hence there can be no tension in them due to the bending moment in the beam. In other cases the bars do not reach

the bottom until within the region of positive moment and part of the stress in the bar at this point will be due to the bending moment. This is well brought out by the curves for beams 384. The minimum stress is shown at gage line 61 for the first bar, at gage line 52 for the second bar, and at gage line 53 for the third bar. Gage lines 53 and 52 are approximately on a vertical line thru the theoretical point of inflection, and gage line 61 is in the compressive zone, and hence there can be no tension in the bars at these points due to bending on this section. Gage line 62 on the second bar and gage lines 45 and 53 in the third bar are in region of positive bending moment and an increase of stress due to the bending moment is to be expected.

Effect of Angle. - To show more clearly the effect on the stresses, of the angle at which the bars are bent down curves were plotted for the first gage line (30) on the inclined portion of the bar and for a point at the mid-depth of the beam for each of the bars. In these curves the angle of bend is plotted as absicissa and the stress is plotted as ordinate. These curves are given on pages 143 to 144, Page 143 gives the curves for beams 382 to 385 inclusive. These beams all have the first bar bent down 8 in. from the support and have 12-in. spaces between bends of the bars. The angle at which the bars are bent down is 32½ deg. in beams 383 and 385 the difference in these being only in the number of bars bent down at each section. At gage lines 31 and 32 the flatter angle, 22 deg. gives a lower stress in all cases, except for the second bar at 200 lb. per sq. in. shear, and the difference in stress becomes more pronounced at the higher unit-shears especially at gage line 31. At this point in the beam there seems

to be very little difference in stress whether the bar is bent down at an angle of $32\frac{1}{2}$ deg. or 45 deg. altho at the higher shearing stress the 45 deg. angle does give slightly higher stresses for both bars. At the center of the beam there is less difference between the stresses for the 22 and the $32\frac{1}{2}$ degree angles, and a little greater difference between the $32\frac{1}{2}$ and 45 degree angles than at the upper position of the beam except for the third bar bent down where the differences are very small in either case but smaller at the center of the beam. In studying the curves for the center of the web of the beam it must be remembered that with the angle of bend the bars cross the center of the web nearer the point of inflection than with the steeper angles and the difference in stress indicated by the curves may be due, at least partially, to the bending moment. The position of gage lines 31, 32 and 33 in all these beams is so nearly identical that there should be no difference in stress for the various beams due to their locations.

On page 144 similar curves are plotted for beams 386 and 393. The horizontal spacing between bars in this case was 8 in. instead of 12 in. as in the previous set. With this spacing there was no beam having the bars bent down at 22 deg.

Effect of Spacing. - The effect of spacing will next be considered. The curves on page 145 are plotted for bars bent down at $32\frac{1}{2}$ deg. and 45 deg. In either case the first bar was bent down 8 in. from the support. These were in four groups of beams having the bars bent down at $32\frac{1}{2}$ deg, 386 with 8-in. spacing, 383 and 384 having 8 and 12-in. spacing and 387 with 16-in. spacing. Only two groups of beams were tested in which the bars were bent

This ¶ on effect of angle should go on preceding page.

down at 45 deg. beam 393 and 384 having 8 and 12-in. spacing respectively.

From the maximum loads carried by the beams having 12-in. spacing no conclusion can be drawn as to which is the most effective angle. From the method of failure it seems that the beams having the bars bent at 22 deg. were more likely to fail by the opening up of a diagonal crack while the beams having the web reinforcement at 45 deg. usually showed a crushing and bulging out of the concrete under the bends before any diagonal crack opened up. The concrete seldom crushed under the $32\frac{1}{2}$ deg. bends.

For the 8-in. spacing beams 386 having bars bent down at $32\frac{1}{2}$ degrees carried a higher load than the average for 393 which had the bars at 45 degrees. Here again there was considerable crushing and spalling under the 45 deg. bends. It was found, as for the beams with 12-in. spacing, that there was very little difference in the stresses in the inclined bars near the points of bending corresponding (gage lines 31, 32 and 33) to differences in the angle of bending down the bars. At mid-height of the beam the differences are also small except for the third bar at the load giving 400 lb. per sq. in shear.

From all the curves on the effect of variation in angle it would seem that the stresses in bars bent down at $32\frac{1}{2}$ deg. or 45 deg. would be about the same but the stresses in bars bent at 22 deg. may be somewhat lower, other things being equal.

For the $32\frac{1}{2}$-degree angle the stress in the inclined portion of the bar near the first bend (gage line 31) increased slightly with the increase in spacing. This is also the case at mid-height of the beam for the bar at the center of the web at the

highest unit-shear. With the 45-degree angle there is not a very large increase in the amount of stress carried by the bars at gage line 31 due to increasing the spacing from 8 in. to 12 in. but at mid-height of the beam the increase in stress is comparatively large being nearly 50%.

The curves for the second and third bars for the 32½ degree and the 45 deg. bends show at the mid-height and at the top of the beam a decrease in stress for an increase in spacing. This is undoubtedly due to the decrease in the bending moment as the point of inflection is approached. The fact that the decrease is less at mid-height of the beam where the effect due to bending is small bears out the above conclusion. In the formula $P = 0.7 \frac{Vs}{jd}$, s is the spacing between the bends of the bars. This formula assumes virtually that the stress in the bent down bar due to shear varies directly with the spacing. At the mid-height of the beam the effect of the bending moment should be small in all cases and according to this formula the stress would be 50% higher for the 12-in. spacing and 100% higher for the 16-in. spacing than for the 8-in. spacing. At the top of the beam the effect due to the bending moment may be considerable but since all beams of the sets compared have the first bars bent down at the same distance from the support the amount of stress due to the bending moment should be the same for gage line 31 in all beams in which the bars are bent at the same angle, and the total stress at gage line 31 should increase with the spacing. This is not borne out by the tests. Only in one case, at the mid-height of the beams having bends at an angle of 45 deg. and spaced 8 in., do the stresses increase as indicated by the above formula. From the appearance of the curv-

es especially those at the mid-height of the beam it seems the total stress carried by the bars bent down may be nearly the same for all spacings used. Calculations of the total stress carried by the inclined bars were made with the results shown in the following table.

TOTAL TENSILE STRESS FOUND IN INCLINED PORTIONS OF BARS.

Location of Stress.	Spacing in.	Angle of bend degrees.	Tensile Stress for Shearing Stress of 400 lb. per sq.in.	Tensile Stress for Shearing Stress of 300 lb. per sq.in.
Top of beam near bend.	8	$32\frac{1}{2}$	53800	33100
		45		31400
	12	$32\frac{1}{2}$		32600
		45		26500
	16	$32\frac{1}{2}$	41800	27600
		45		
At mid-height of beams.	8	$32\frac{1}{2}$	32600	19000
		45	36200	20900
	12	$32\frac{1}{2}$	33800	18400
		45	36800	22700
	16	$32\frac{1}{2}$	30600	14700
		45		

From the results given above it is seen that the mid-height of the beam where the effect of the bending moment is small the spacing of the web reinforcement has no apparent effect. At the top of bend, that is at the upper end of the inclined portion of the

bar, the reduction of stress in the second and third bar down due to bending moment is sufficient to reduce the total stress carried by all the bars in the beam to a lower value for the beams having the greater spacing. The lowest value at the top of the bend is always greater than the maximum value for the mid-height in a given beam for the same load thus indicating that part of the stress at the top of bend is due to the bending moment. If the total stress carried by the bars remains constant regardless of the spacing between bars, as the tests appear to indicate, the formula $P = 0.7 \frac{Vs}{jd}$, as given above, cannot be correct unless a different interpretation is placed upon it. If s is defined as the total length of the beam to be reinforced by the web reinforcement and P is the total load carried by all the bent down bars we would have the condition that the total stress in the web reinforcement due to shear remains constant regardless of the distribution of the reinforcement. Such a result is not unreasonable and is in fact rather to be expected when it is considered that the concrete has a great deal of lateral stiffness and its strength in direct shear is sufficient to distribute the shear to the bars even tho' the spacing does vary. However, any statement that total shear which a certain amount of steel will carry will remain the same regardless of the distribution, must be qualified. It must be understood that all the steel is effective in taking shear and every portion of the beam must be protected so failure cannot take place without crossing the steel.

In all the previous analysis it has been found that the effect due to any variable has been obscured to a great extent by the effect due to the bending moment which necessarily changes

with some of the variables For example it is impossible to have two beams with different spacing without having a different bending moment at the corresponding bars. An attempt has been made to eliminate this effect. The first assumption made was that the stress in a bent down bar near the top of the beam is equal to the sum of the stresses due to flexure and shear. If this is so and it is possible to calculate the stress in any bar due to flexure and subtract this stress from the measured stress, the remaining stress must be caused by shear. To make such calculations several assumptions were necessary. The principal ones are, (1) that an inclined bar which is some distance below the horizontal steel carries its proportion of the bending stress, consideration being taken of its distance from the neutral axis, and (2) that the stress in the inclined bar is the same as if it were horizontal at the point considered. With these assumptions it was possible to calculate approximately the stress in the inclined bars at various points due to flexure alone. If the above assumptions are all true and the results obtained are approximately correct the stress due to shear alone at two different points in the same bar should be the same. Such stresses were calculated for gage lines 30's and 40's for several beams and the results plotted from the same origin. These curves are shown on pages 149 to 150. The calculated flexural stress was in all cases reduced to about 87%, of the full value since it was found that gage line 2 over the support usually showed about 87% of the theoretical stress. Considering the uncertainties in calculating these values it is believed that the curves for the two gage lines on the same bar check each other rather closely. Although this is not conclusive,

it indicates that the stress in the inclined bar is equal to the sum of the stress due to flexure and that due to shear. If the average of each two of these curves is produced back it will cut the line of zero stress at a shearing unit stress of from 150 to 225 lb. per sq. in. This would indicate that from 150 to 200 lb. per sq. in. of the shear at any time is carried by the concrete and not a certain fraction of the shear. In the formula, $P = 0.7 \frac{Vs}{jd}$ if s is taken as the total length of beam to be reinforced it hardly seems that the full distance from the load point to the support should be used. Diagonal tension is not likely to occur much inside of a line drawn from the support an angle of 45 degrees. Subtracting 17 in. from the distance to the load point we have $s = 31$ in. Calculating the stress in the inclined bars with this value of s it was found that the slope of the line thus obtained corresponded quite closely with the slope of the curves [illegible] shown, the curves generally being slightly steeper. That is, the rate at which the inclined bars take stress is less than the formula would indicate. From appearances at failure the maximum spacing used was not enough to affect the maximum load a beam would carry. In no instance did a diagonal crack form between two bars without crossing them.

Effect of Distance from Support to First Bend. On Pages 147 to 148 are given the curves showing the effect on the stresses of varying the distance of the first bend from the support. The actual stresses at gage lines 30 in the first and second bars bent down are not greatly affected by the distance from the support to the first bend. They seem to decrease with an increase in the distance but undoubtedly this is due to the decrease in stress

due to flexure. The curves do not indicate that the distance from the support to the first bend was too great in any case. Comparing the maximum loads carried by beams 386, 391 and 392 no great difference is found altho with the increase inthe distance to the first bend there is a slight decrease in the load carried.

Beams 386.1 and 386.2 check each other very well on the maximum load carried as do also 391.1 and 391.2. Beam 392.1 failed at a shearing unit-stress of 352 lb. per sq. in. as compared with 430 lb. per sq. in for 392.2. The great distance from the support to the first bend may account for this uncertainty of action. If this is so, the indication is that for safe construction smaller distances from the support to the first bend should be used. There is nothing in the manner of failure or in the ultimate loads carried by beams 393 , 394, and 395 , to indicate that the distance from the support to the first bend had any effect on the strength of beams.

Beams 396 , 397 , and 398 , show the effect of varying the distance from the first stirrup to the support. The curves on pages 133 to 135 show the stress in the stirrup for various unit-shears. Curves for beams 396, in which the first stirrup was 8 in. from the support, show that the maximum stress is not in the first stirrup but in the second. For beam 397 the stress is the highest for the first stirrup and for 398 there is practically no stress in the second stirrup. It seems that for these beams the maximum distance from support at which a stirrup may be expected to take appreciable load for is 20 in. The total stress carried by the stirrup appears to be nearly constant for a given shear. A comparison of the maximum loads carried shows a lower average

value for beams 398. than for the other of the groups having stirrups closer to the support. Beam 396.2 carried the lowest load of the six but this was probably due to some fault in fabrication. This beam failed at the outer end before any signs of failure appeared between supports and in a very peculiar manner. In beam 398.1 the stress in the first stirrup passed the yield-point at about 300 lb. per sq. in. shearing stress. There is not any conclusive evidence to show that a stirrup 16 in. from the support and having sufficient area to carry the shear would not be safe construction. It appears that the total stress carried by the stirrups for the different beams remains constant for a given vertical shear. At the higher shearing unit-stresses the total stress carried by the stirrups was about 45% of the total external shear.

Other Beams. - Beams 388 and 389 did not belong to any particular set of beams. Beam 388 had four bars bent down at an angle of $32\frac{1}{2}$ deg. 14 in. from the support. Beams 389 were the same with two stirrups added as shown in the drawings. In none of these cases do the steel stresses in the inclined bars exceed those over the support altho beam 389.1 did fail by diagonal tension across gage line 41. The primary cause of failure for both beams 388 was a slipping of the straight bars. Beam 389.2 failed by tension at the center causing crushing of the concrete.

CONCLUSIONS.

Within the range covered in these tests the following conclusions seem to be warranted.

1. The total stress carried by a system of inclined bars is not affected by the horizontal spacing between the bars.

2. The tensile stresses in the inclined bars at equal loads on the beams, are approximately the same for bars bent at $32\frac{1}{2}$ and 45 degrees. Bars bent at 22 degrees show considerably smaller stresses.

3. Beams in which the reinforcement is bent down at $32\frac{1}{2}$ degrees with the horizontal are likely to fail by diagonal tension before the ultimate strength of the steel over the support is reached if the distance from the support to the first point of bending down a bar is equal to the depth of the beam or greater than the depth of the beam. A distance of three fourths of the depth of the beam from the support to the first point of bending down a bar will prevent such diagonal tension failures.

4. For beams having the web reinforcement at 45 degrees with the horizontal there is little danger of a diagonal tension failure between the support and the first bend if this distance does not exceed the depth of the beam. It is considered advisable to bend the first bar down at some point less than the distance _d_ from the support.

5. For vertical stirrups a distance from the support to the first stirrup equal to the depth of the beam is not dangerous if sufficient stirrup steel is provided to carry the stress at this point. The total stress to be carried may be as high as .45 V where V is total external shear at the support. Stirrups more

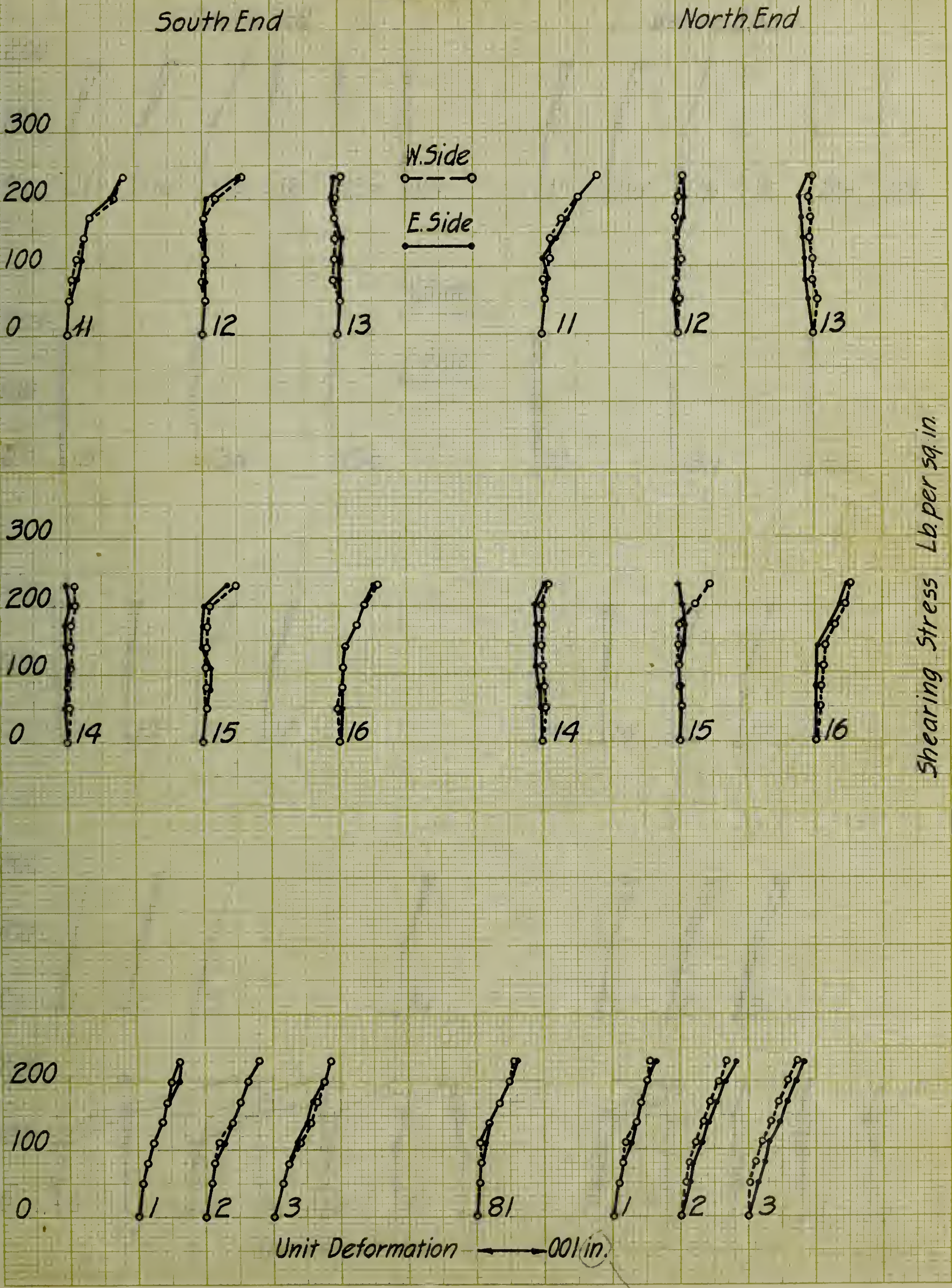
than 1.25 d from the support receive no stress and the stirrup located at a distance of from $\frac{3}{4}$d to d from the support receives the maximum stress.

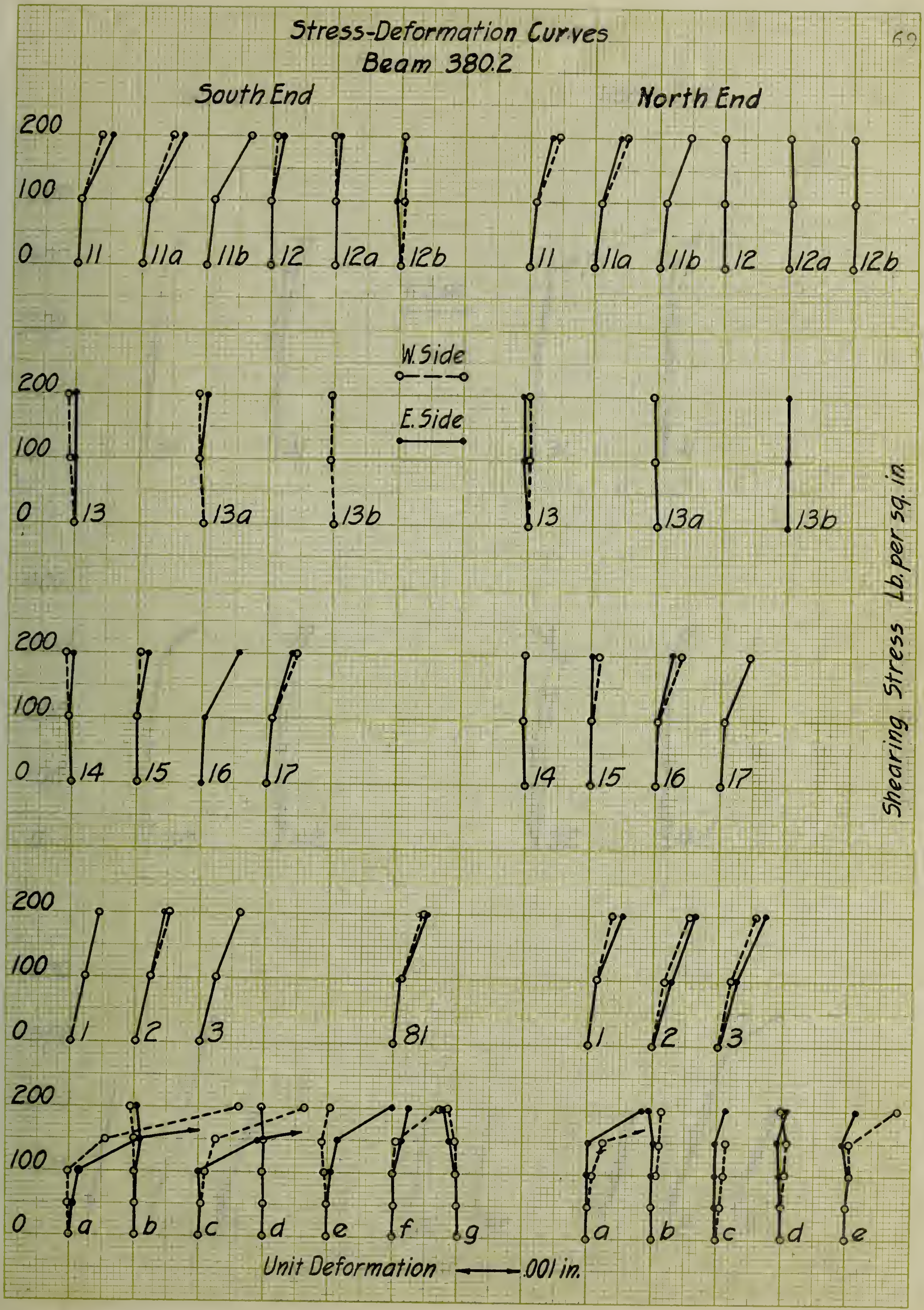
6. In a formula such as $T = \frac{Vs}{jd}$, the formula recommended by the Joint Committee, for the stress in an inclined web member, s should be taken as the total length of the portion of the beam subject to diagonal tension failure and T as the total stress carried by all the bars within this portion of the beam. The concrete carried a shearing unit-stress of about 175 lb. per sq. in. before web reinforcement began to take any stress due to shear. In the above formula S may be taken as some value less than the total length to be reinforced. The amount by which this length may be reduced is about $\frac{3}{4}$ d or perhaps as much as d. It should correspond to the smallest distance from the support at which a diagonal tension crack will occur.

7. With any amount of steel up to two percent it should be possible to bend down enough bars and at such points that the tensile strength of the steel in bending can be developed before a diagonal tension failure occurs.

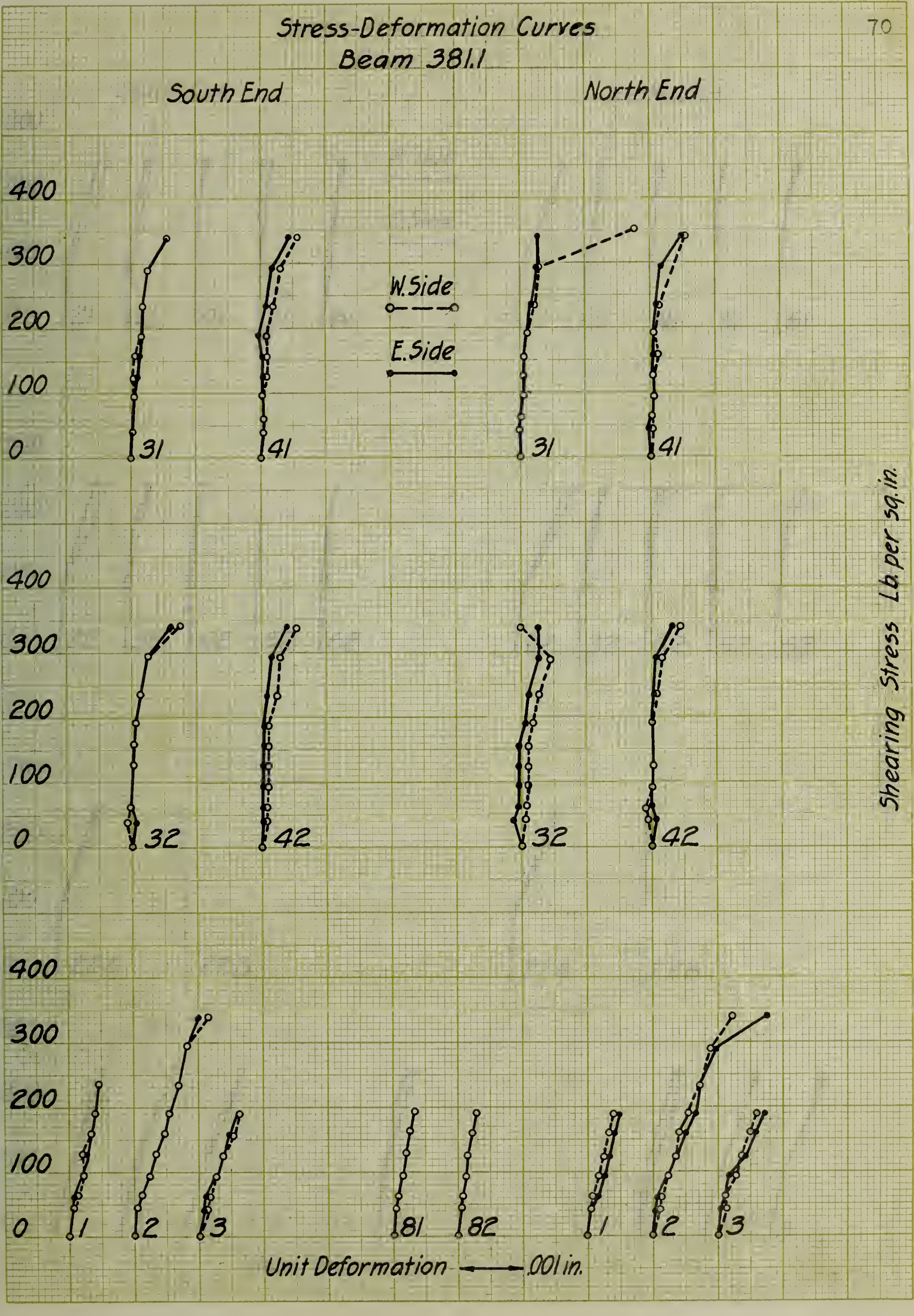
8. Crushing is more likely to occur under the bends of the bars when bent at a steep angle than when bent at a flat angle.

Stress-Deformation Curves
Beam 380.1

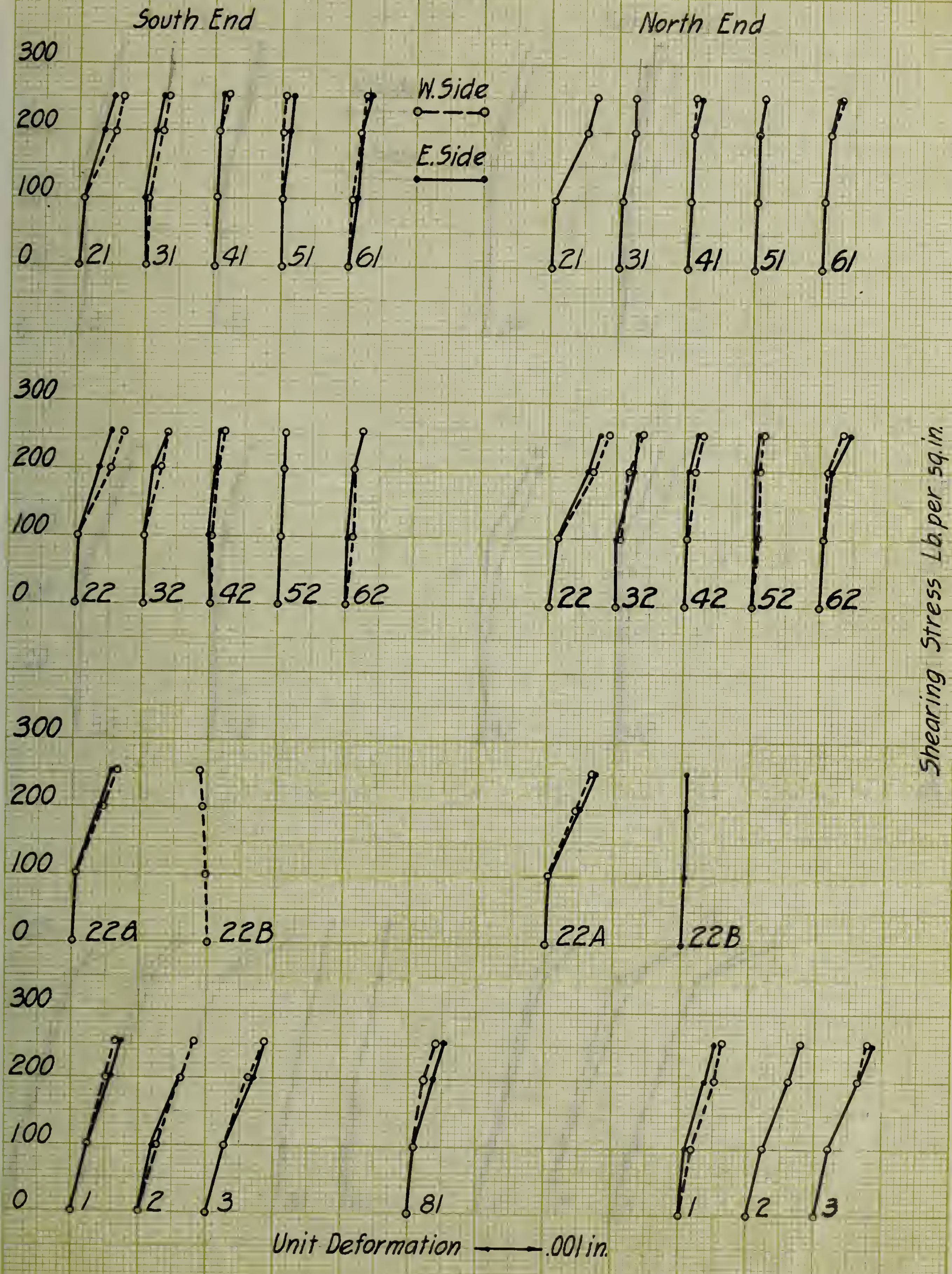


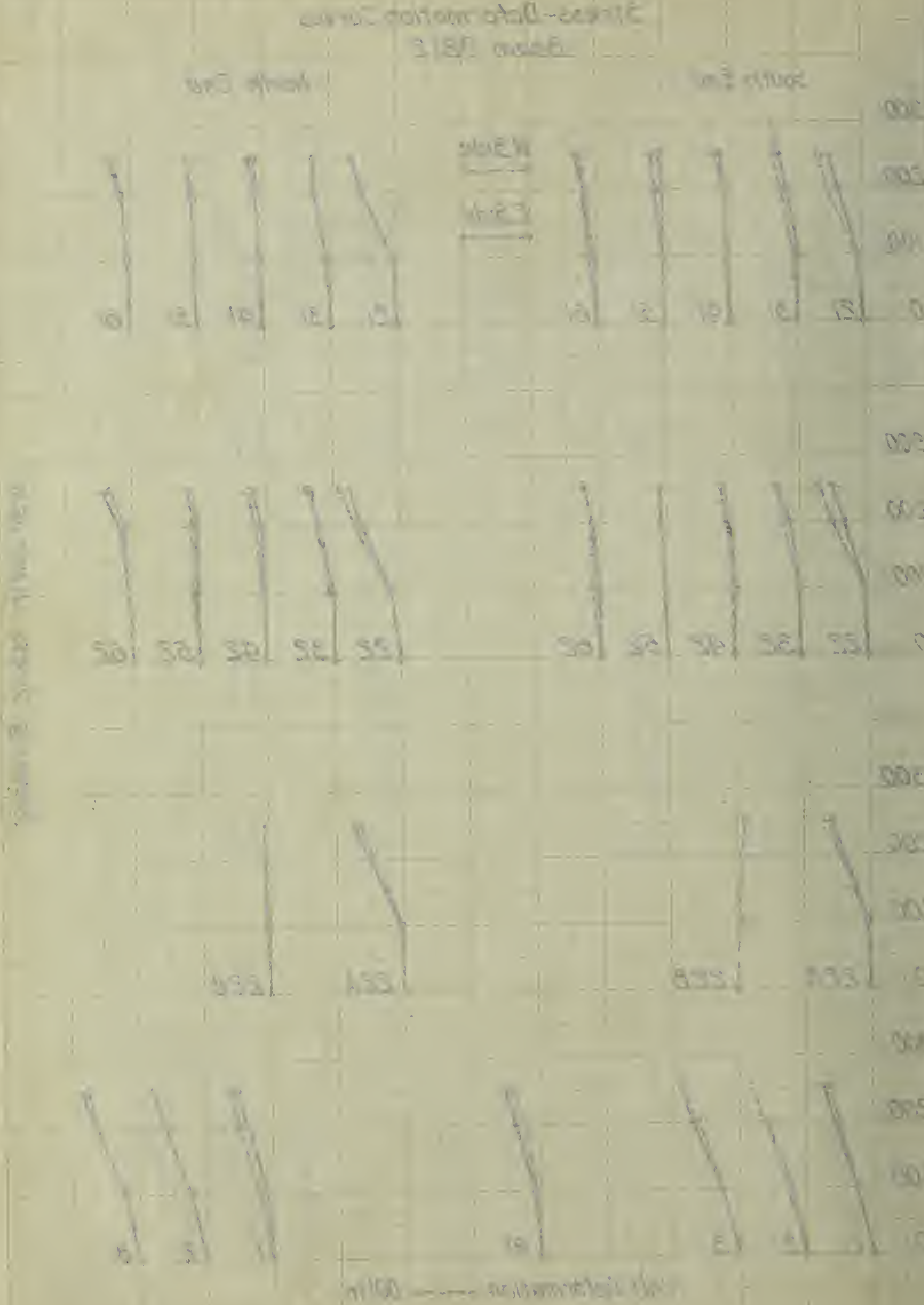


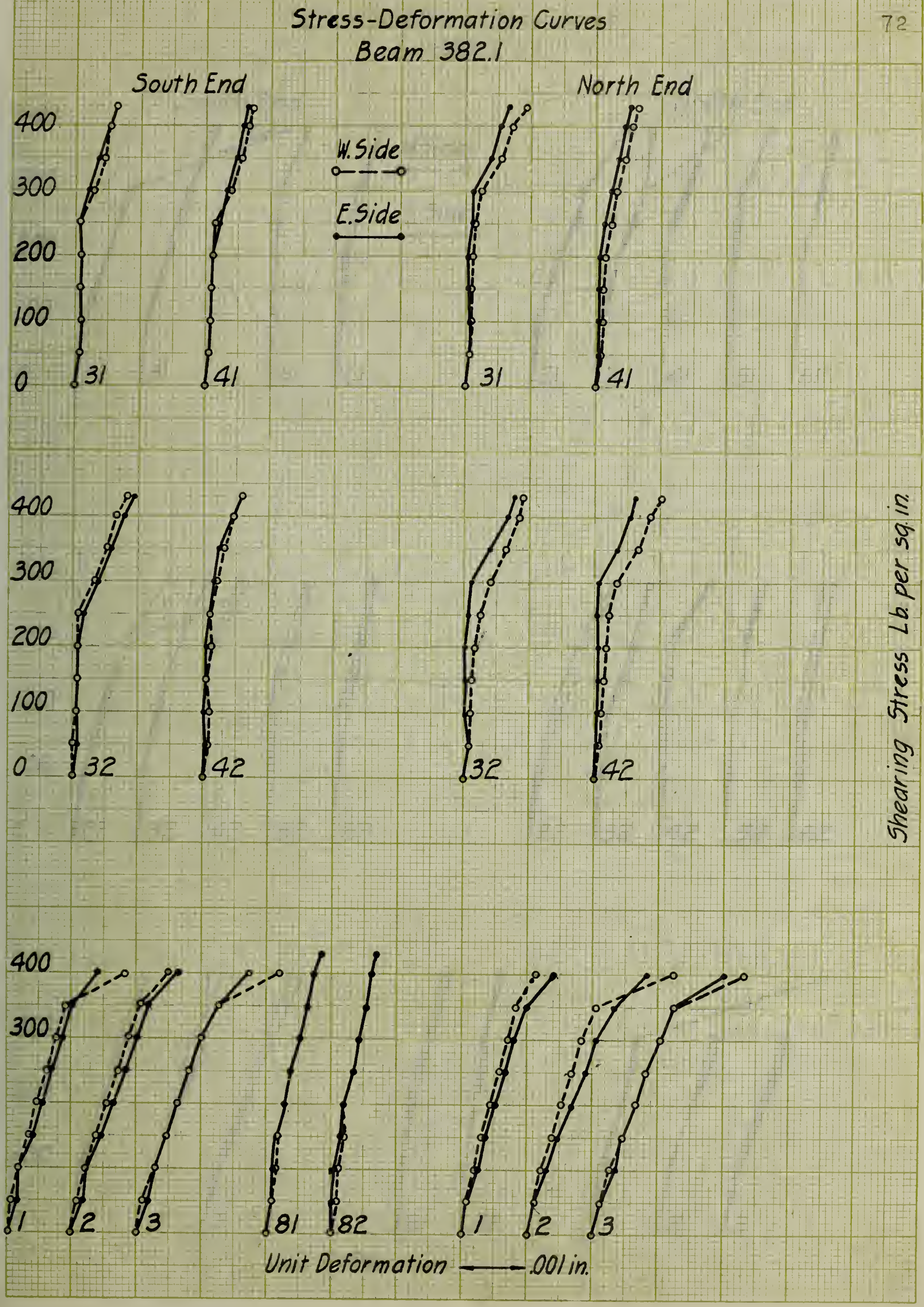
Stress-Deformation Curves
Beam 380.2
South End
North End
200
100
0
11
11a
11b
12
12a
12b
W. Side
E. Side
13
13a
13b
14
15
16
17
1
2
3
81
a
b
c
d
e
f
g
Unit Deformation
.001 in.
Shearing Stress Lb. per sq. in.

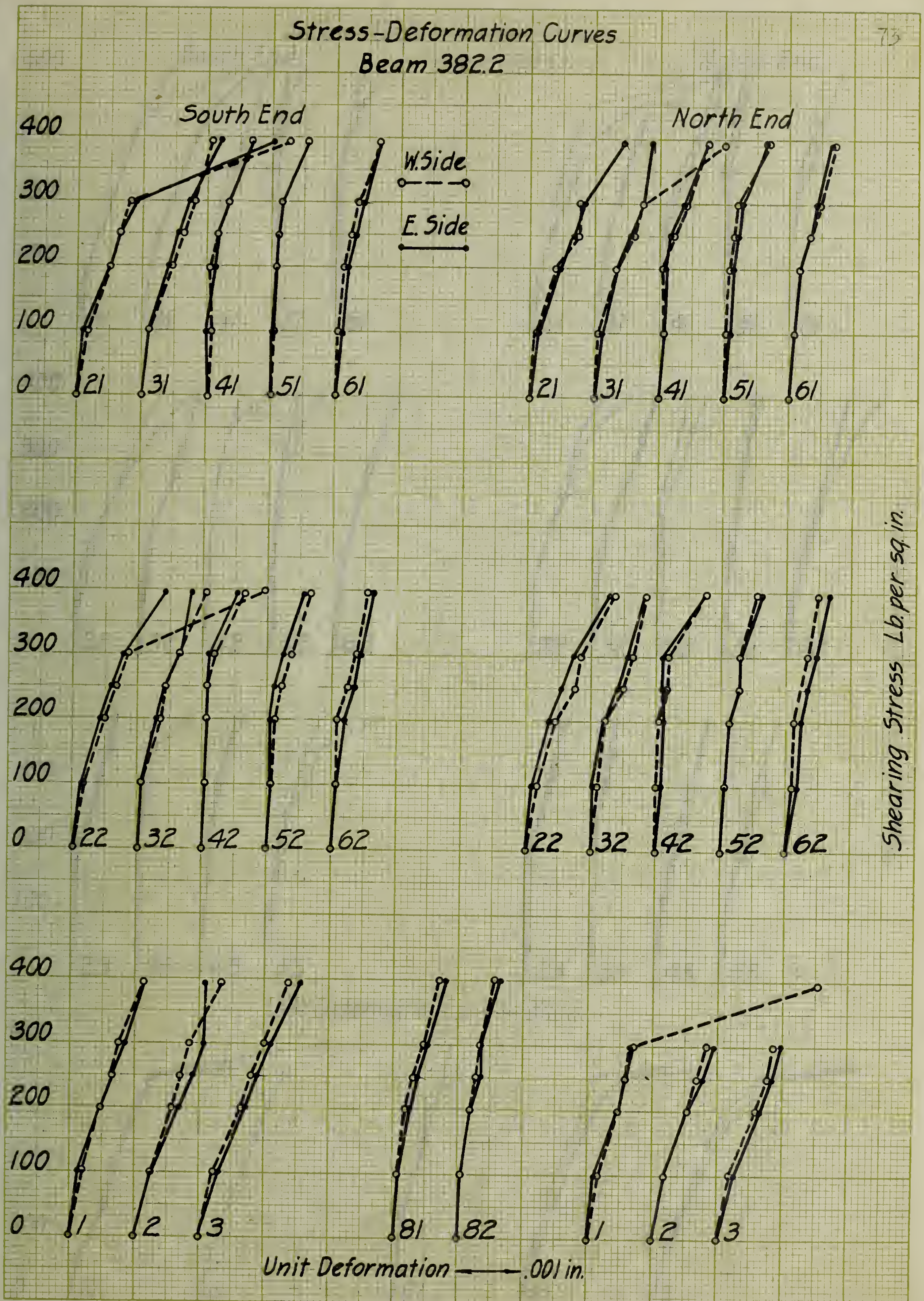

Stress-Deformation Curves
Beam 381.1
South End
North End
W. Side
E. Side
400
300
200
100
0
31
41
32
42
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.

Stress-Deformation Curves
Beam 381.2

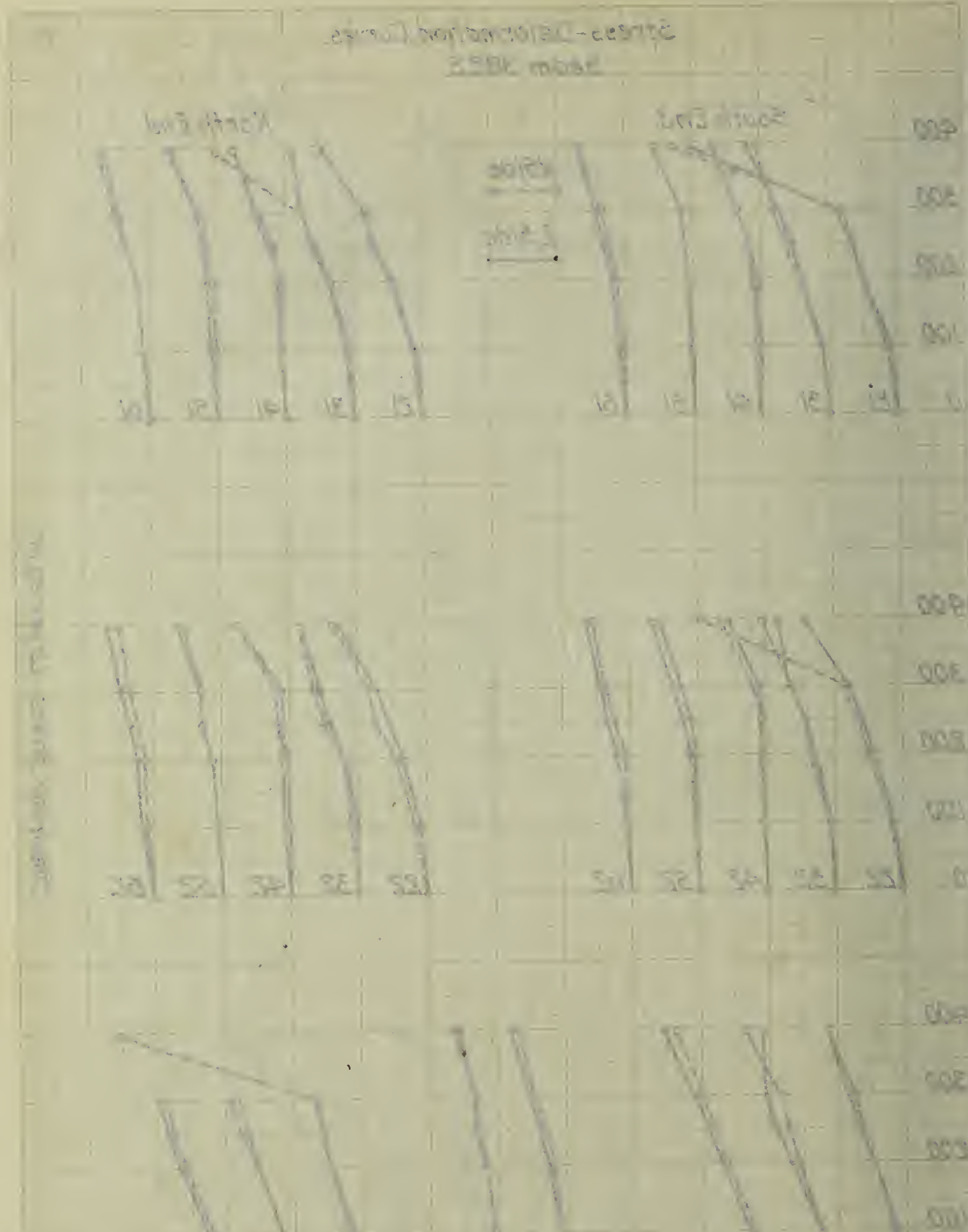




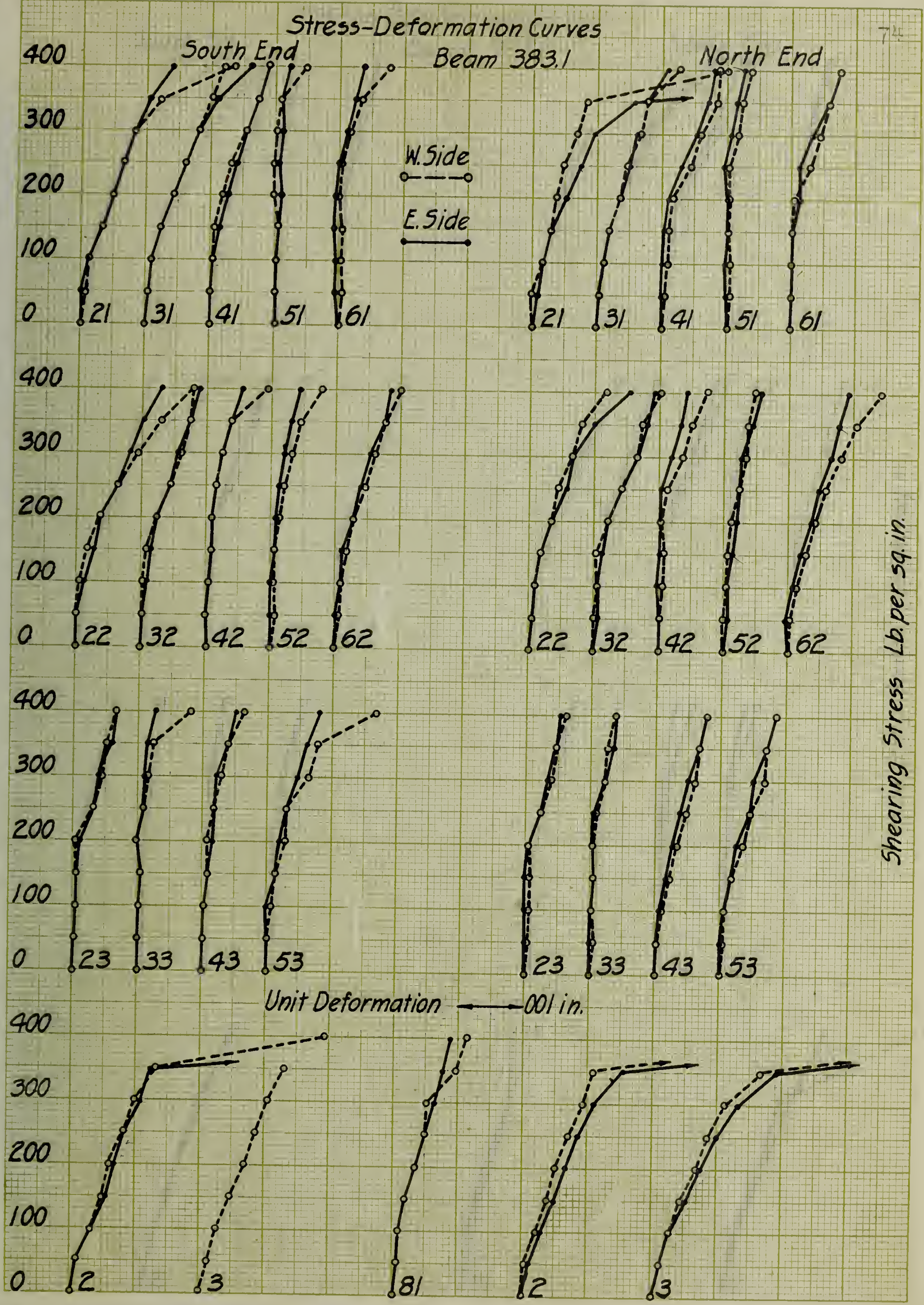

Stress-Deformation Curves
Beam 382.1
South End
North End
W. Side
E. Side
400
300
200
100
0
31
41
32
42
1
2
3
81
82
Unit Deformation ——— .001 in.
Shearing Stress Lb. per sq. in.



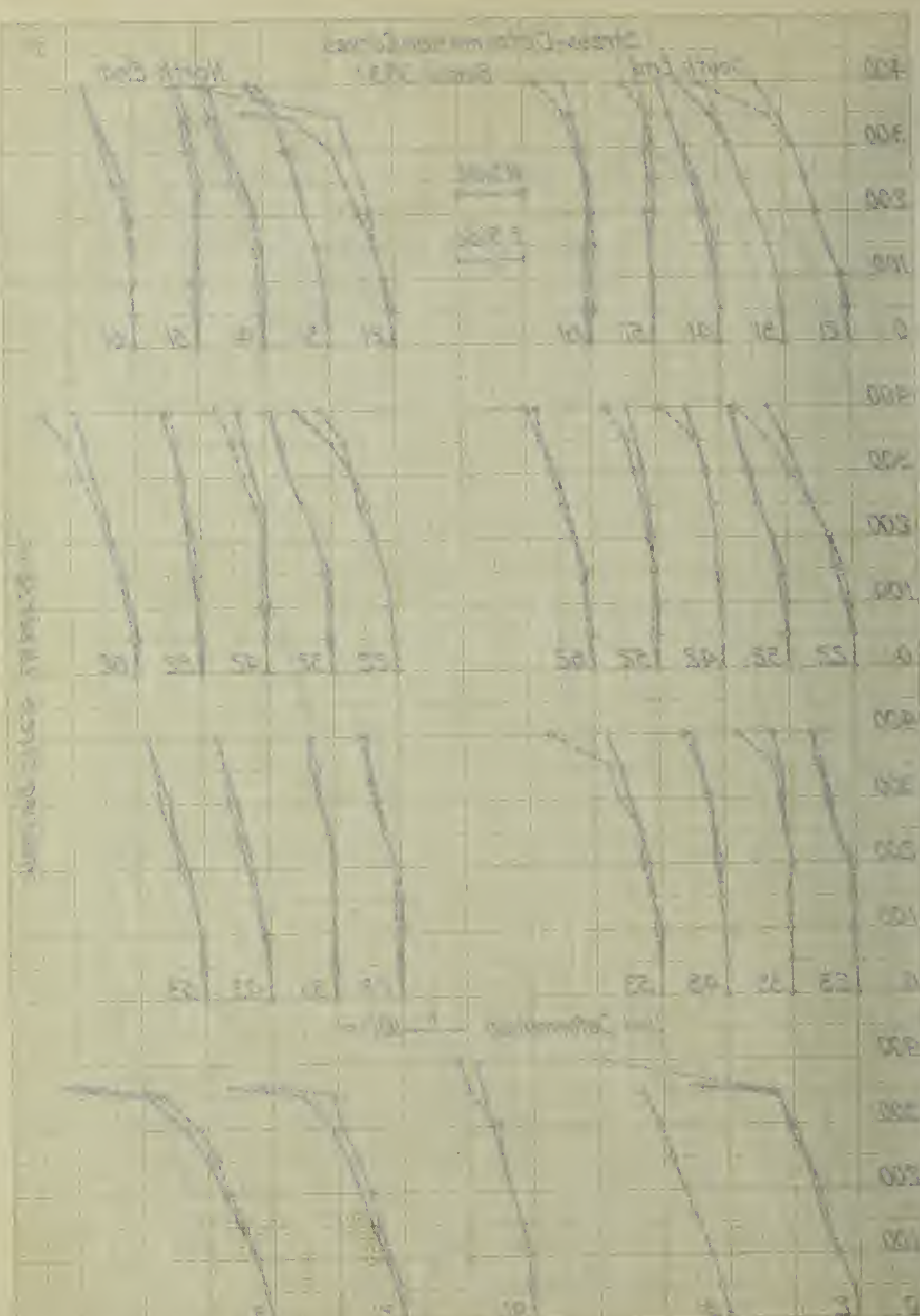
Stress-Deformation Curves
Beam 382.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

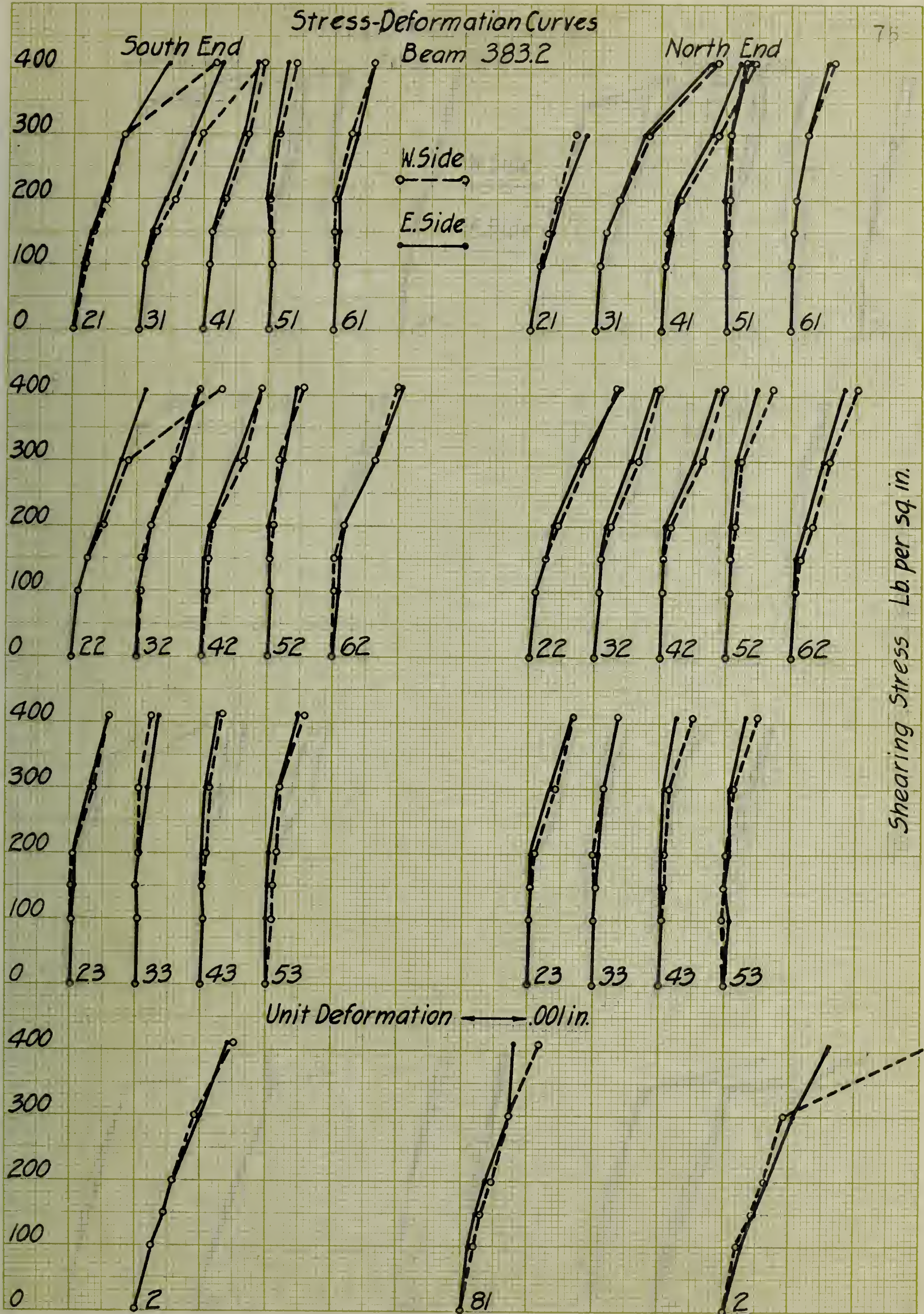


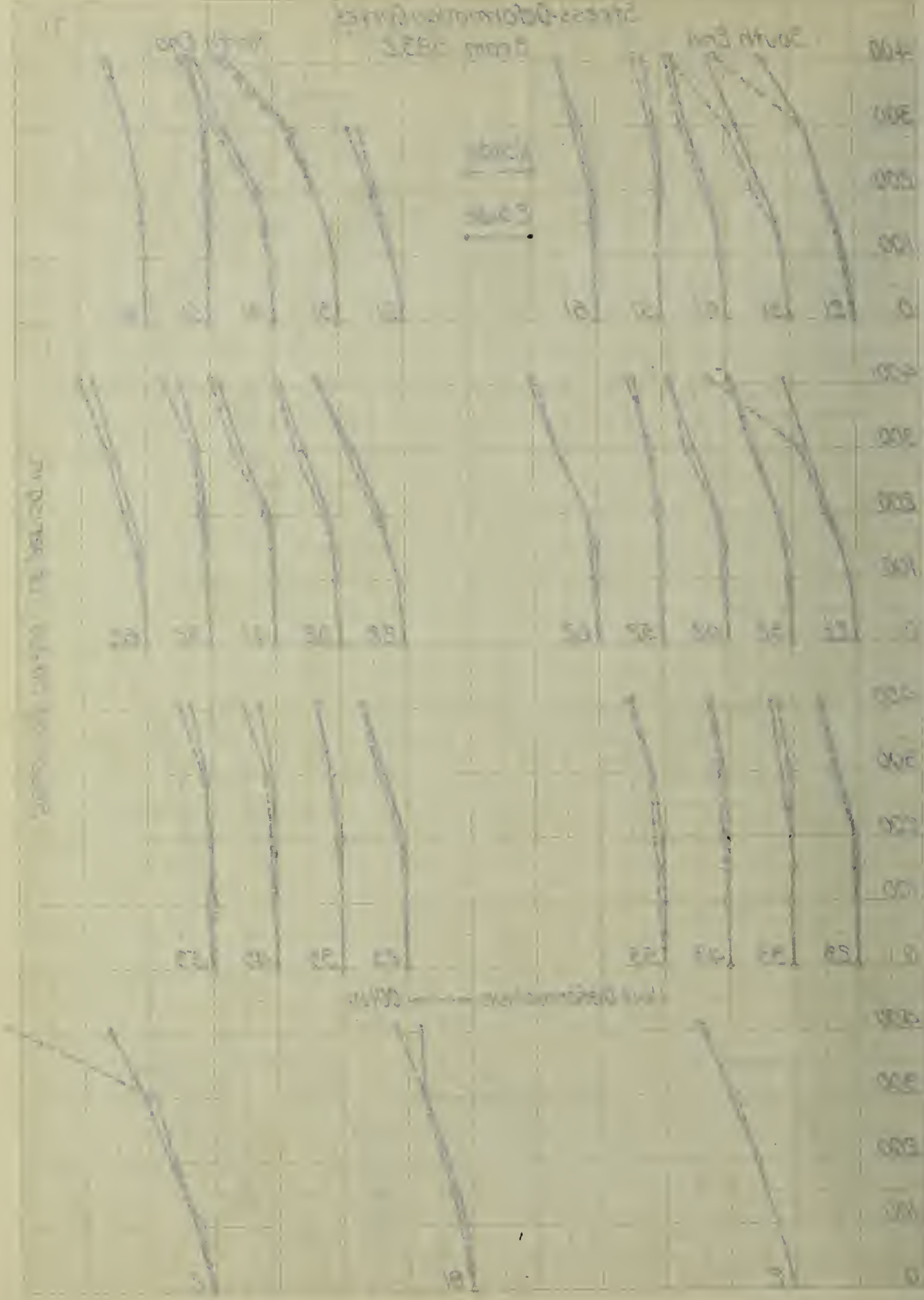
Stress - Deformation Curves
North End
South End

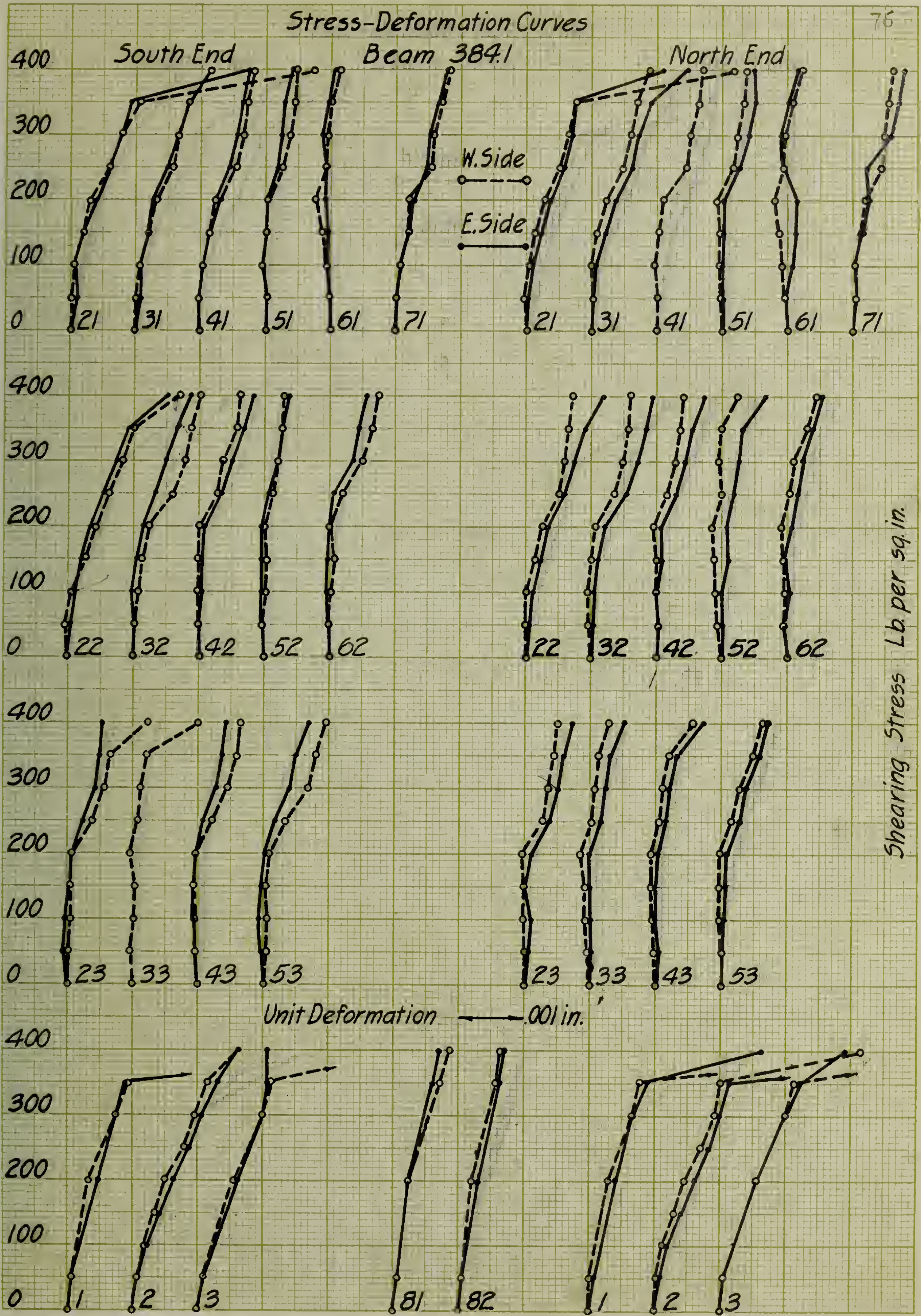


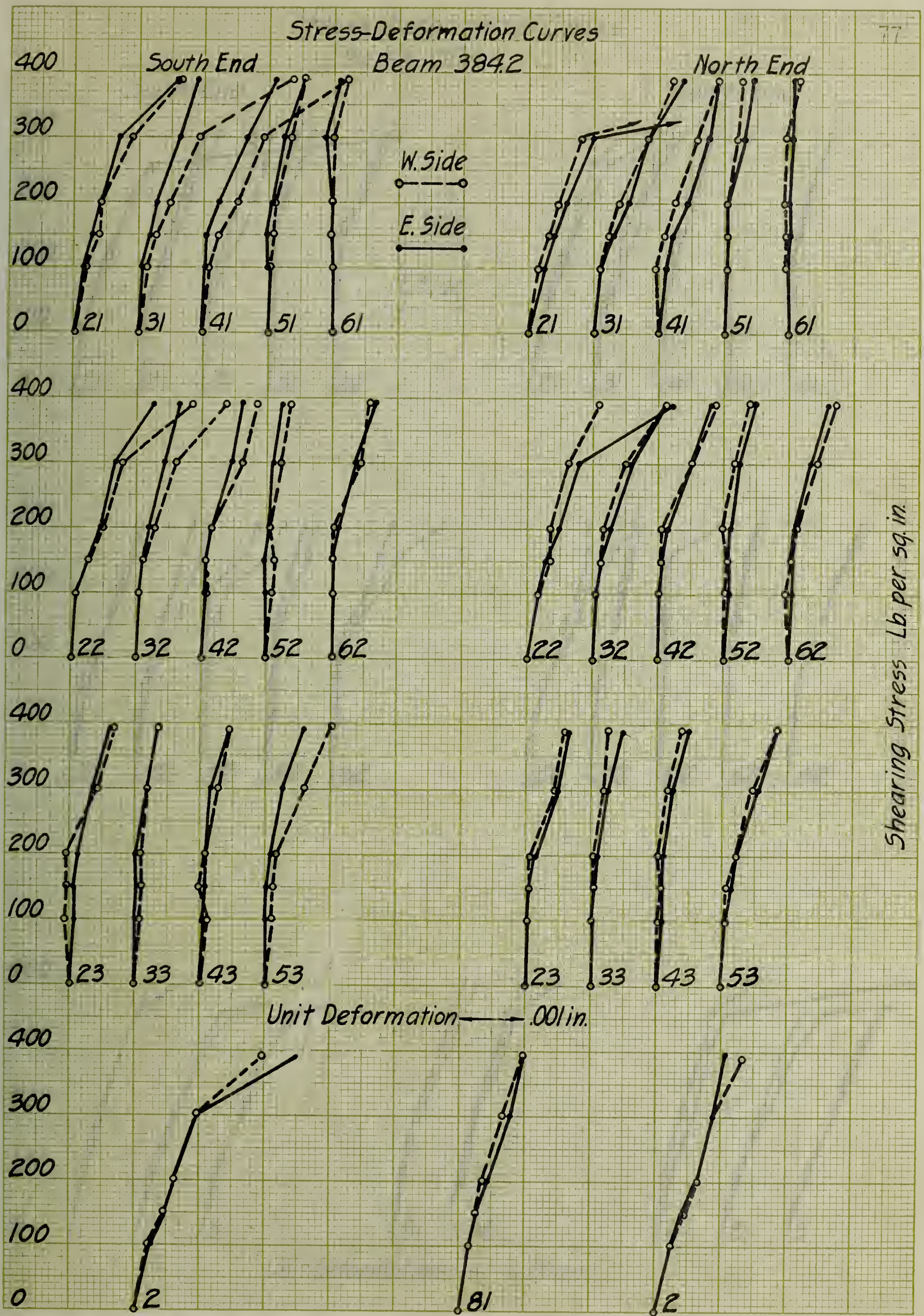
Stress-Deformation Curves
Beam 383.1
South End
North End
W. Side
E. Side
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
2
3
81

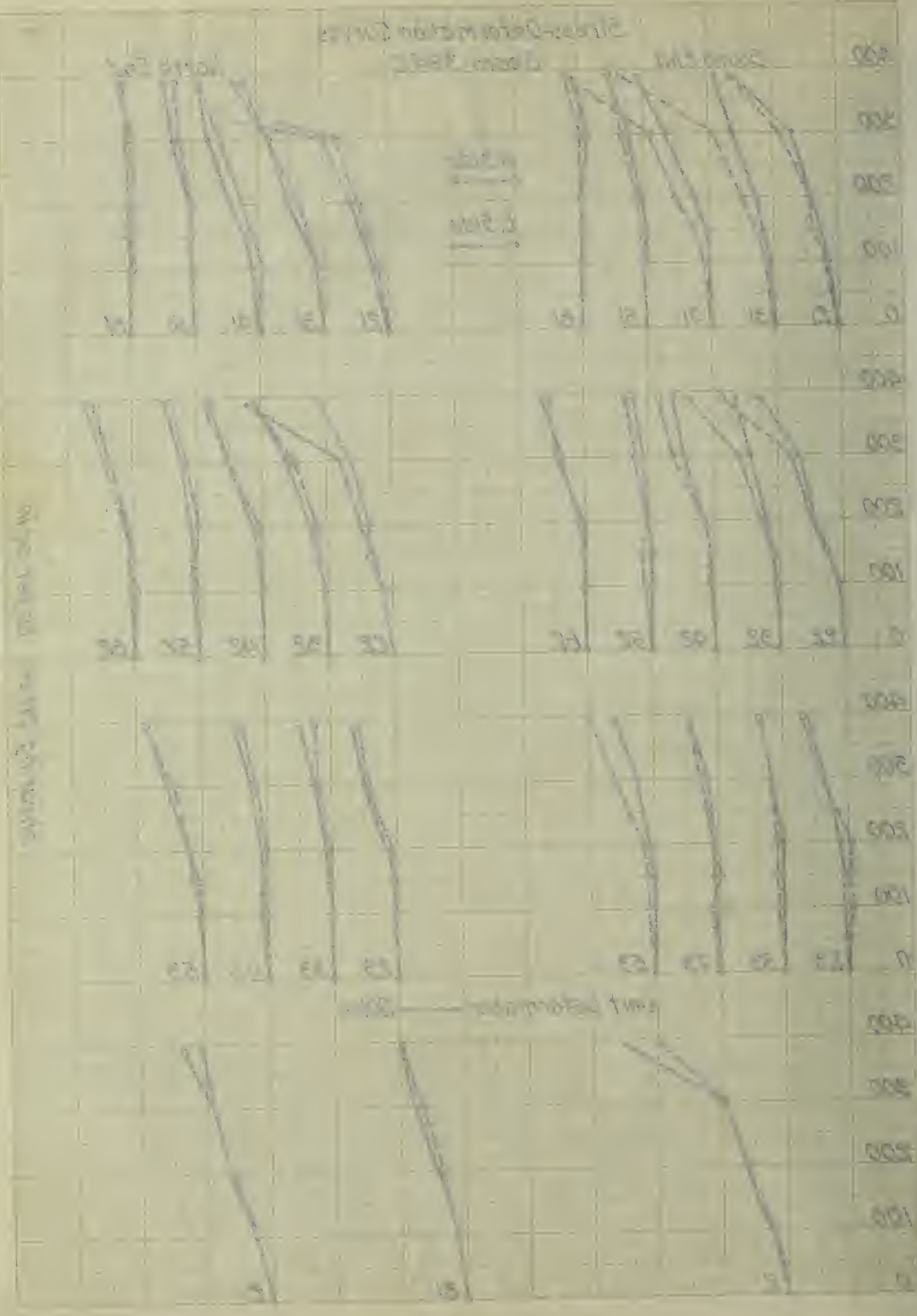


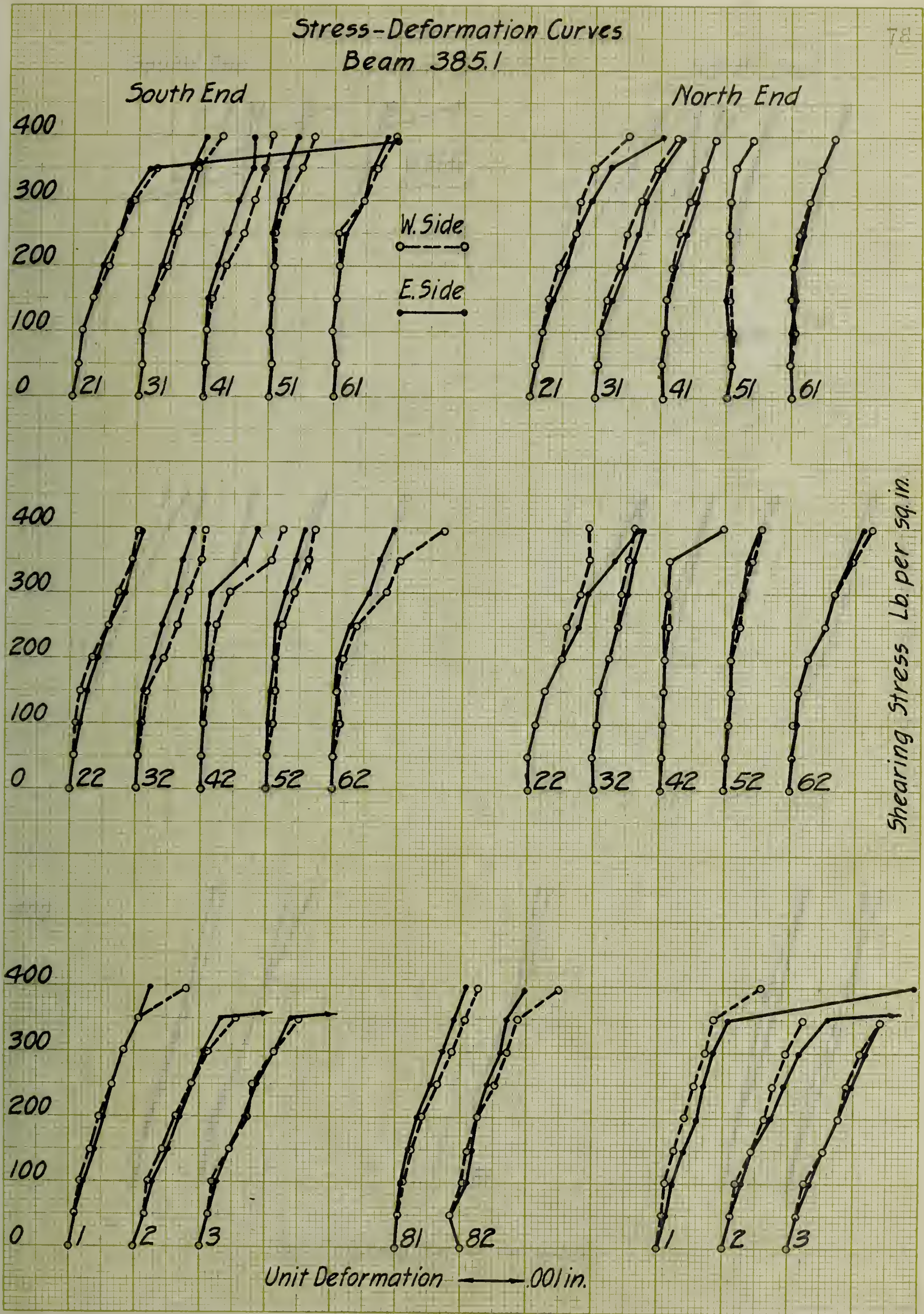

Stress-Deformation Curves
Beam 383.2
South End
North End
W. Side
E. Side
0
100
200
300
400
21 31 41 51 61
22 32 42 52 62
23 33 43 53
2
81
2
Unit Deformation ←→ .001 in.
Shearing Stress Lb. per sq. in.

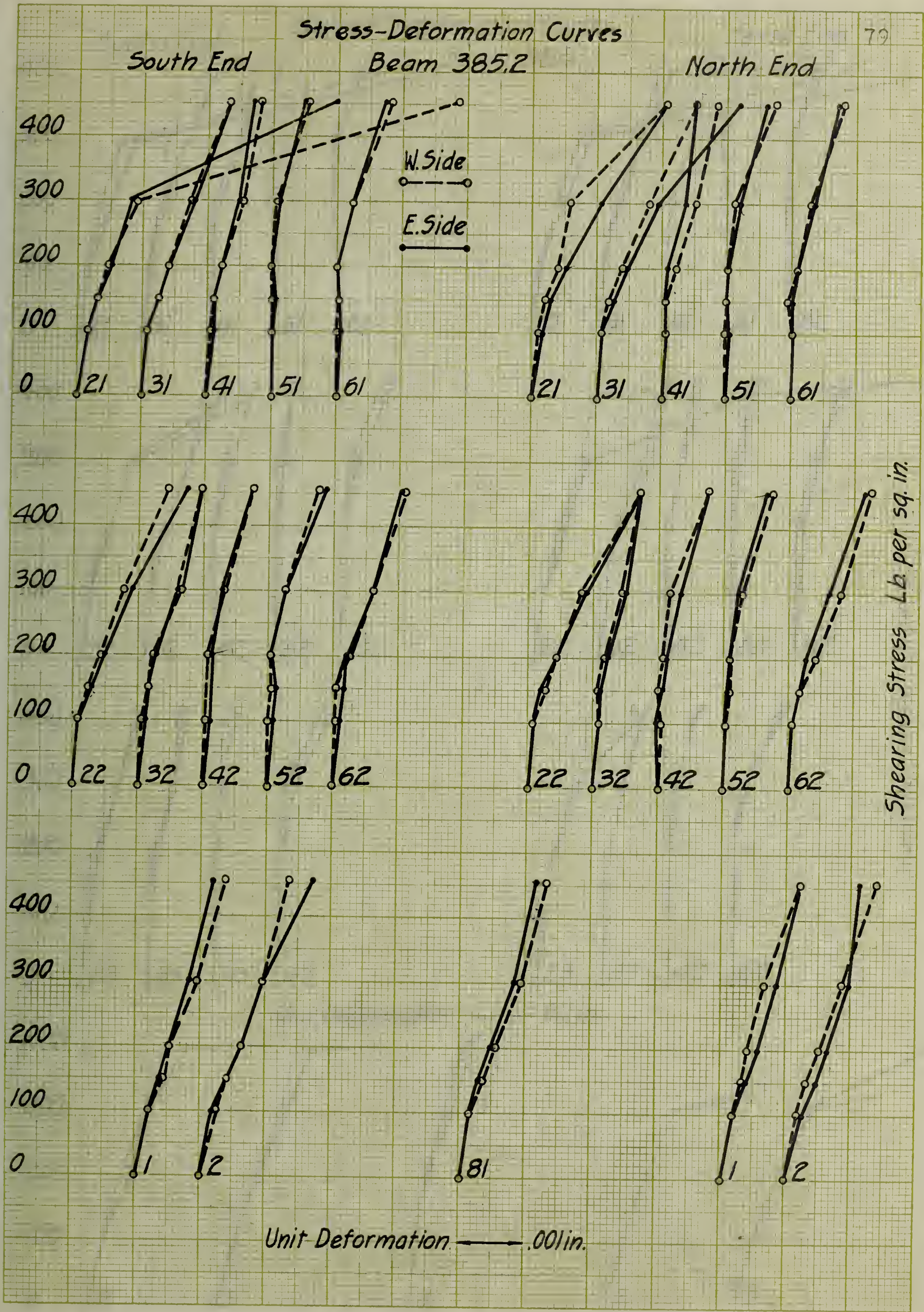



Stress-Deformation Curves
South End
Beam 3841
North End
W. Side
E. Side
Unit Deformation —— .001 in.
Shearing Stress Lb. per sq. in.
400
300
200
100
0
21 31 41 51 61 71
22 32 42 52 62
23 33 43 53
1 2 3 81 82

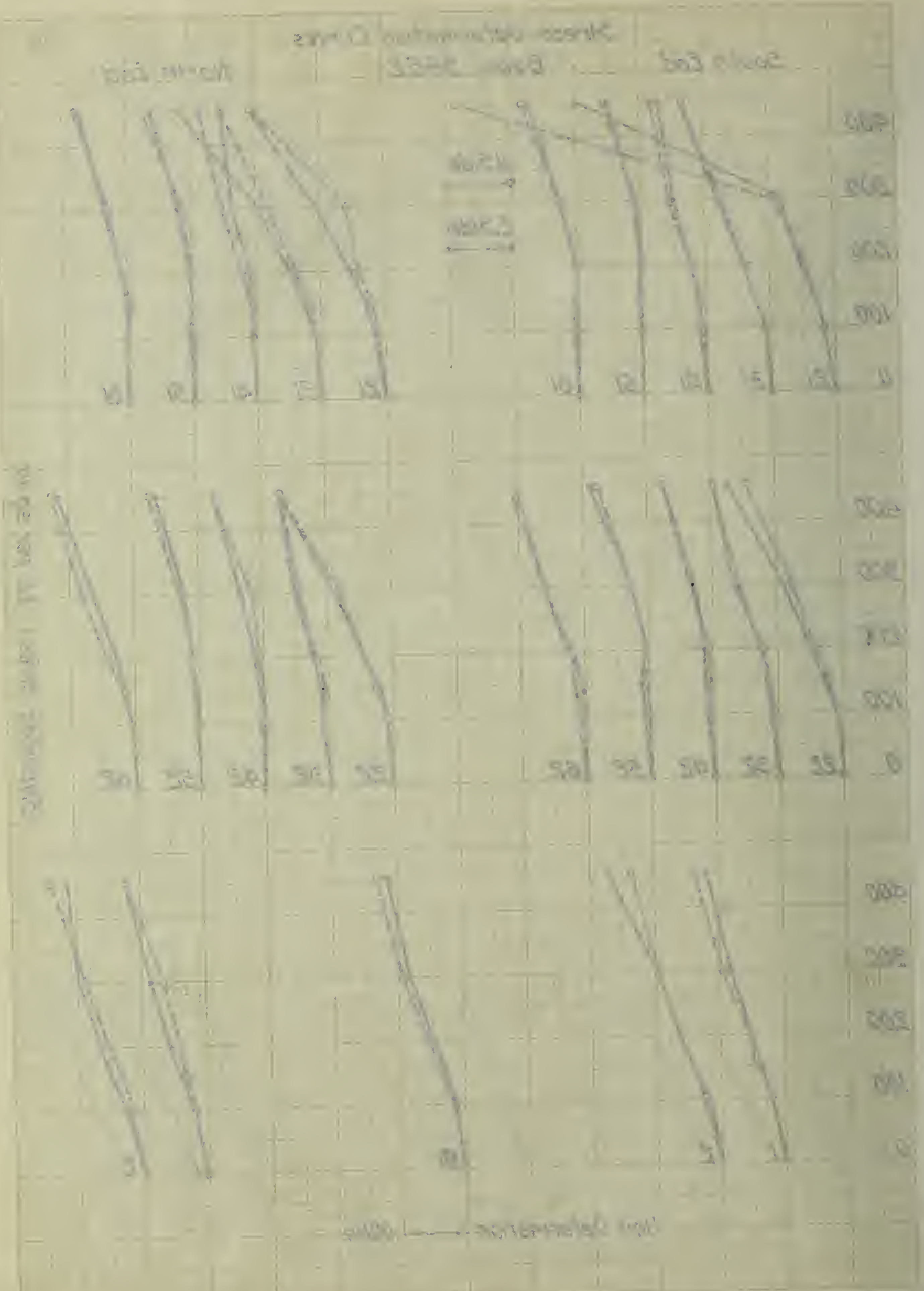

Stress-Deformation Curves
Beam 384.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
2
81
Unit Deformation ←→ .001 in.
Shearing Stress Lb. per sq. in.

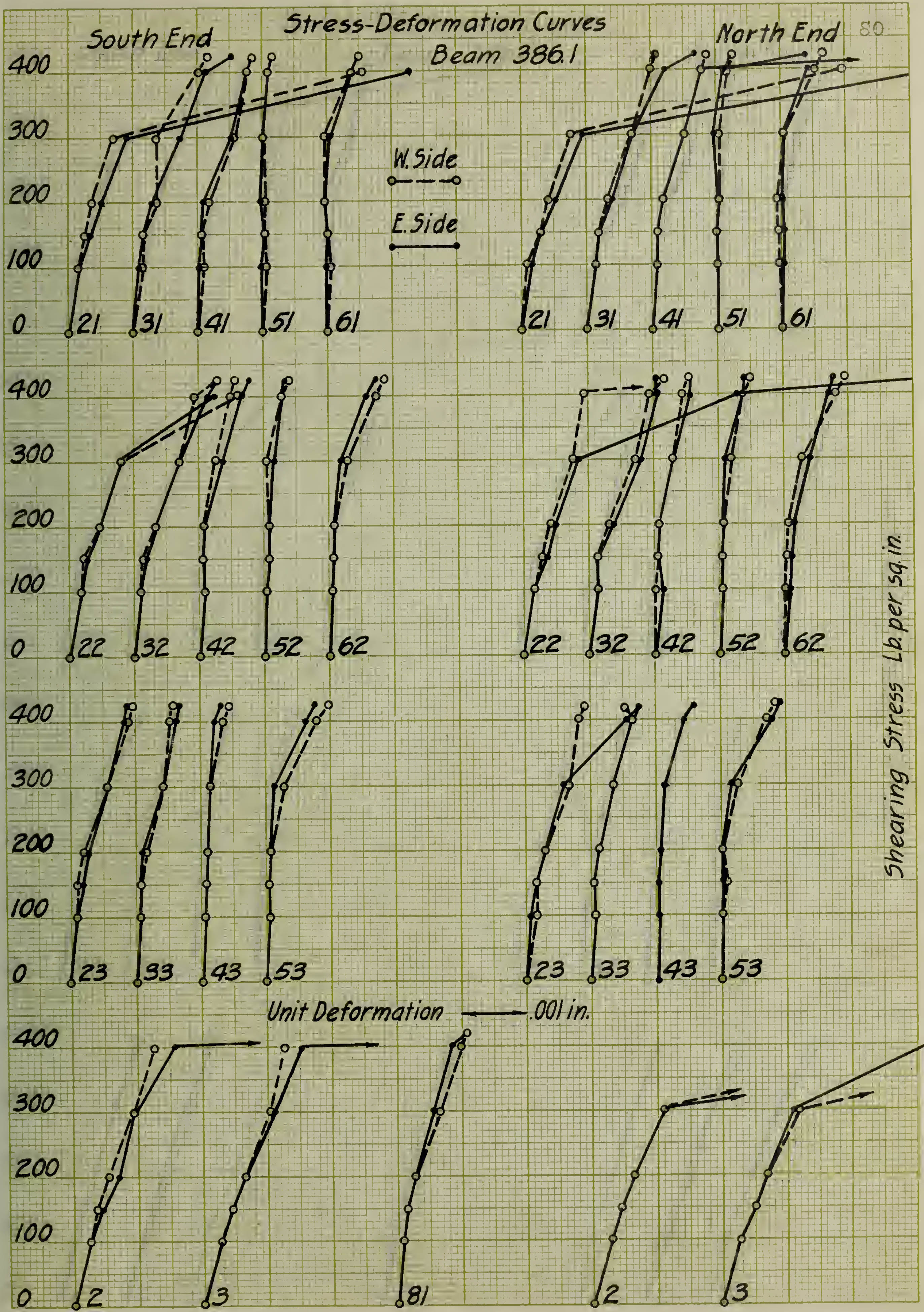


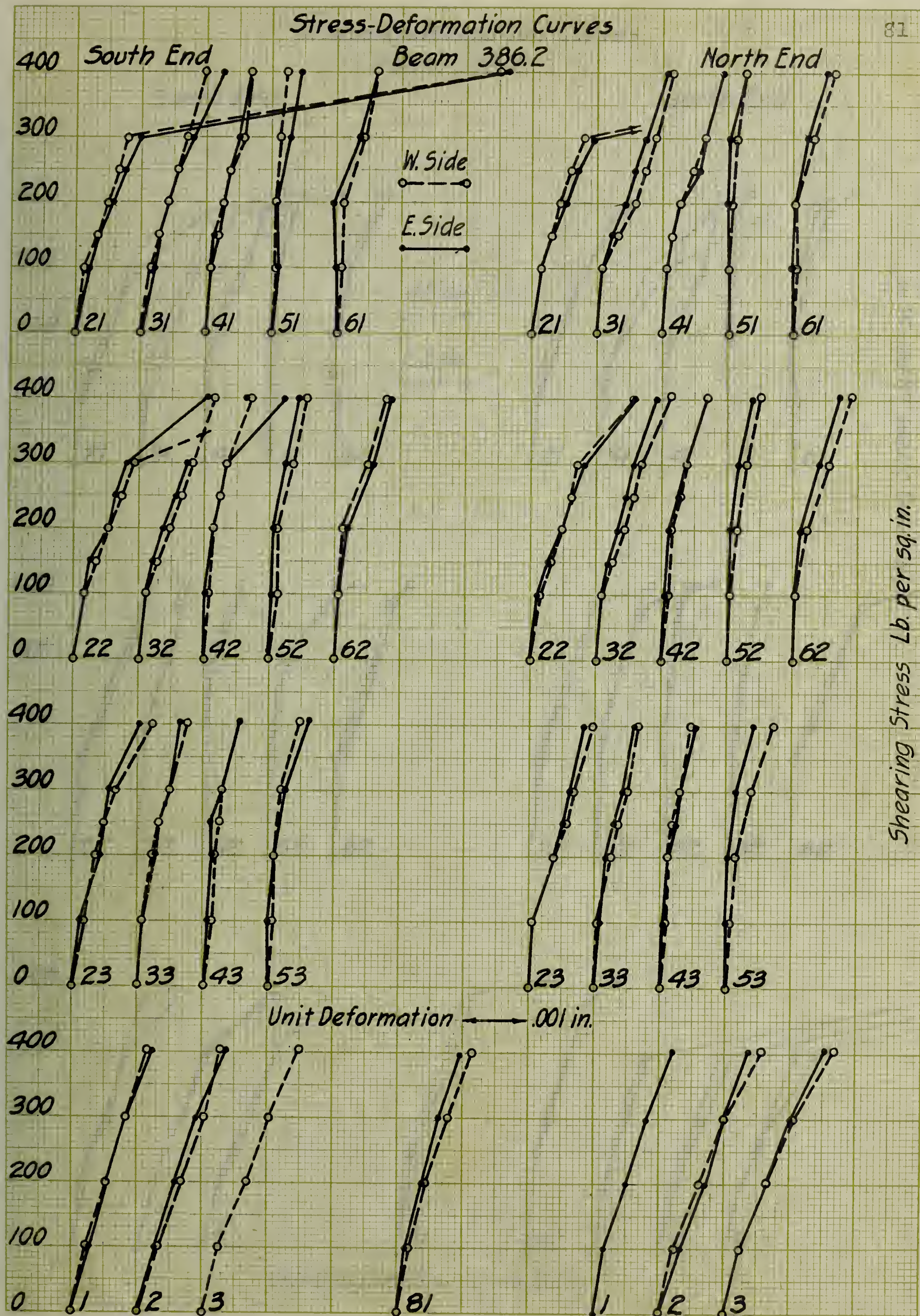

Stress-Deformation Curves
Beam 385.1
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

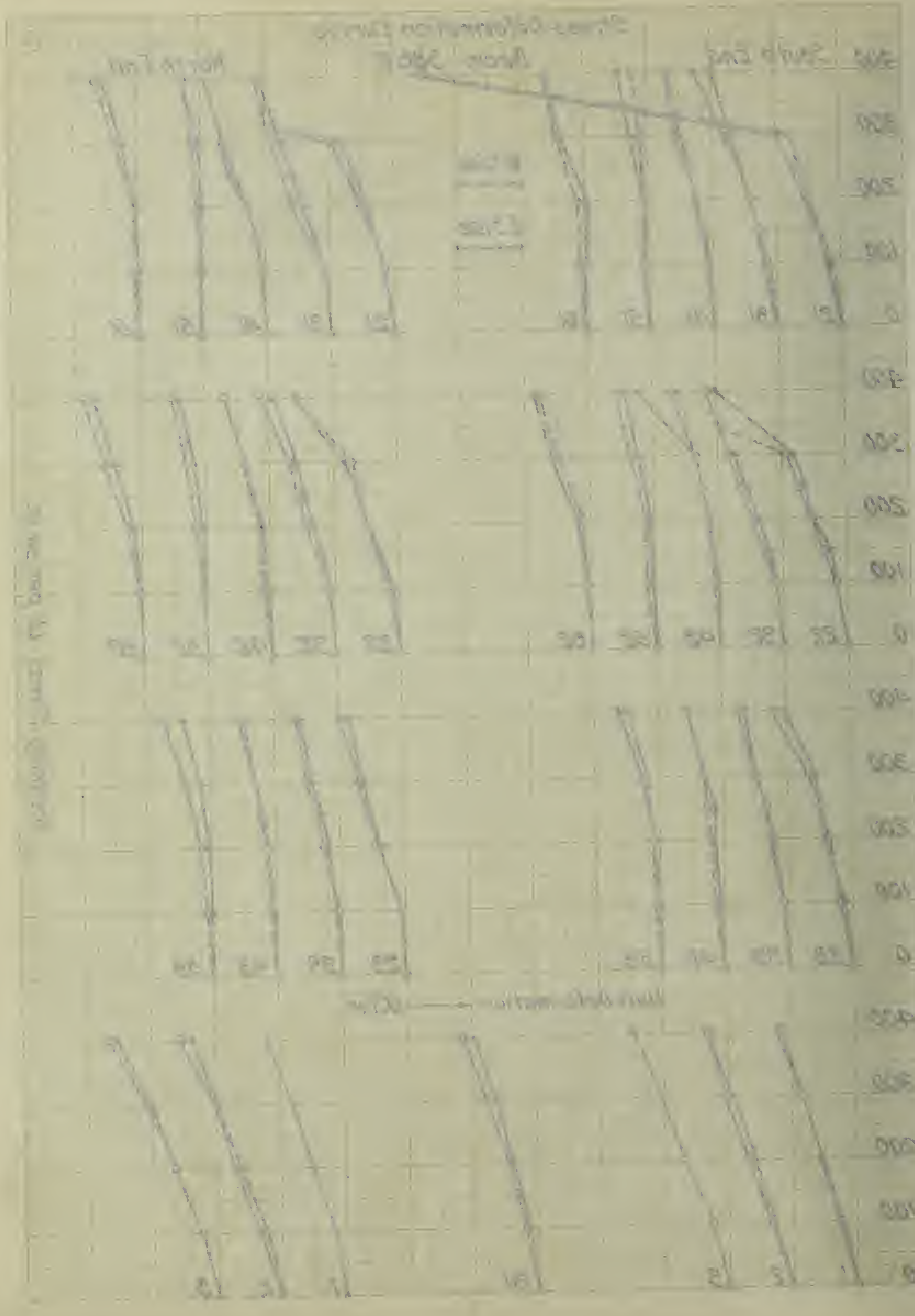


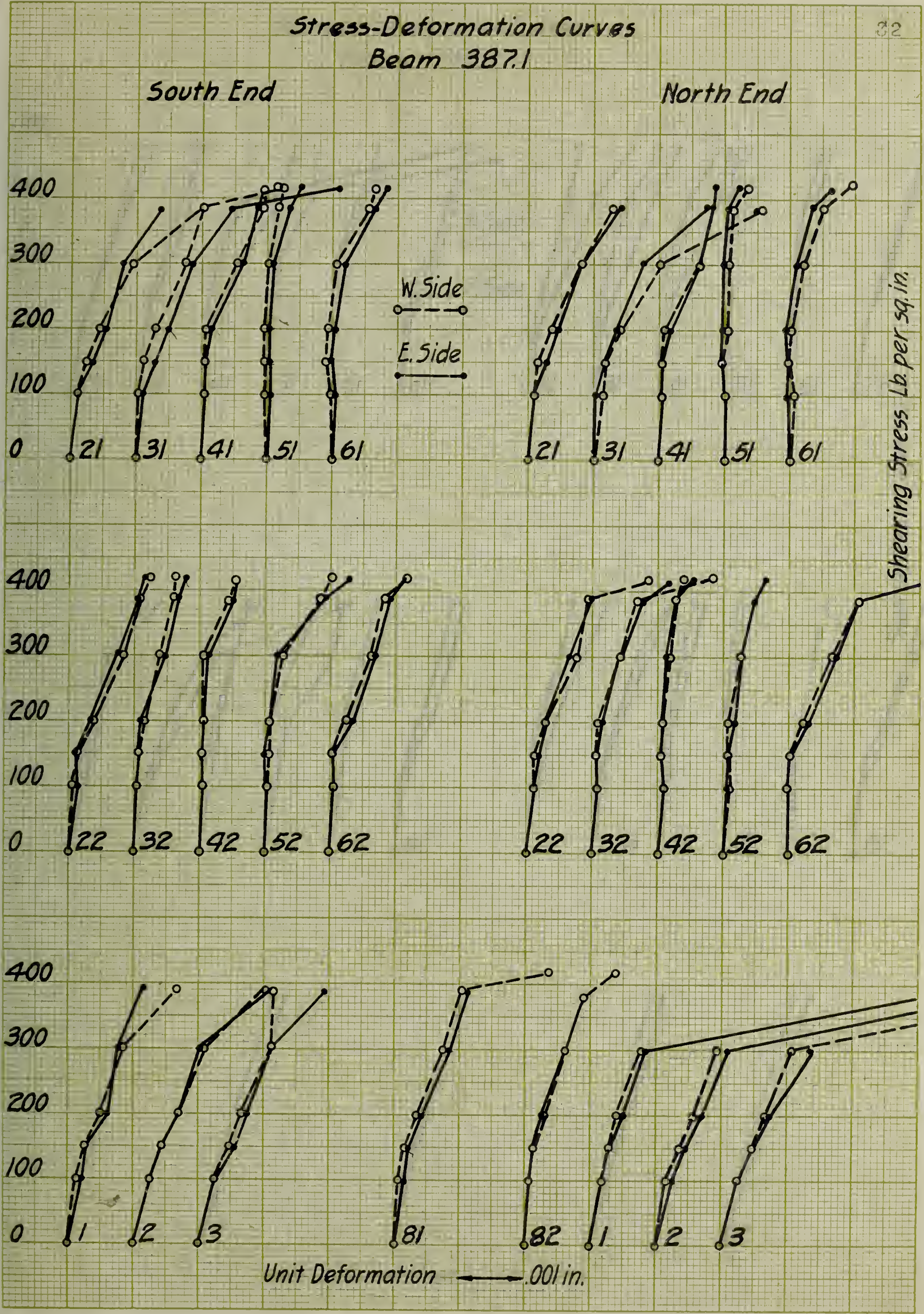
Stress-Deformation Curves
South End
Beam 385.2
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
1
2
81
Shearing Stress Lb per sq. in.
Unit Deformation ——— .001 in.

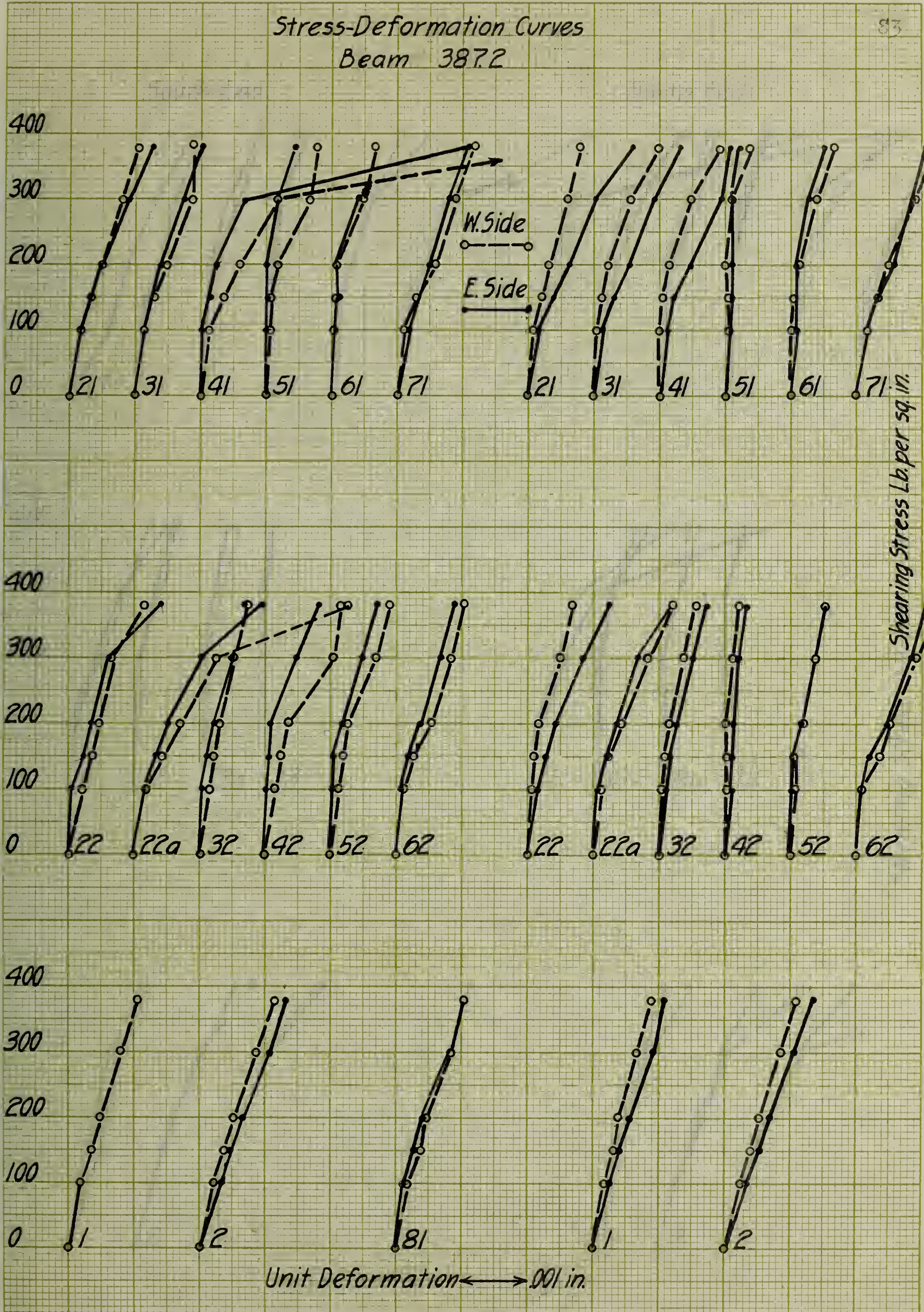


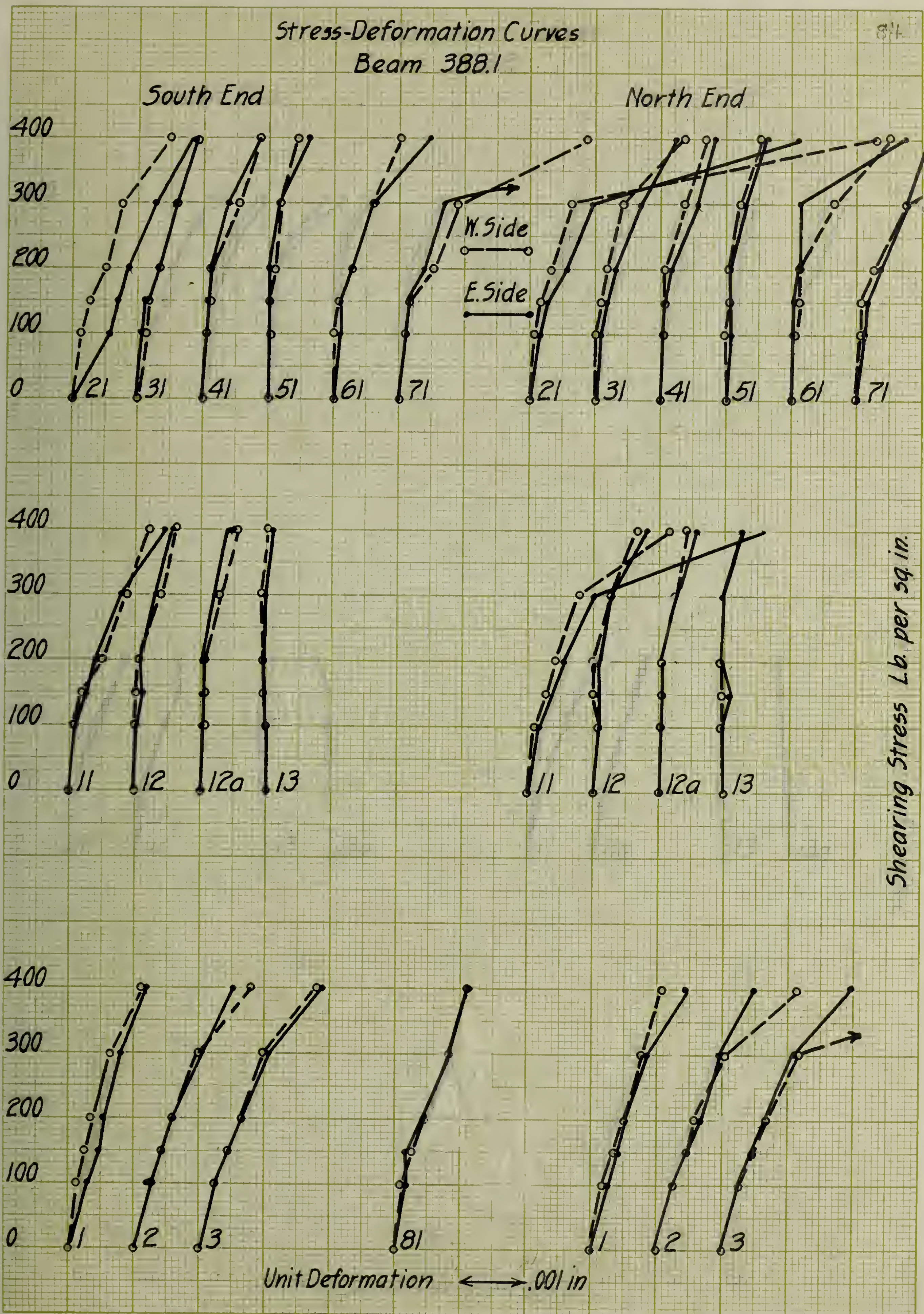

Stress-Deformation Curves
Beam 386.1
South End
North End
W. Side
E. Side
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.
0
100
200
300
400
21
31
41
51
61
22
32
42
52
62
23
33
43
53
2
3
81


Stress-Deformation Curves
South End
Beam 386.2
North End
W. Side
E. Side
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
1
2
3
81

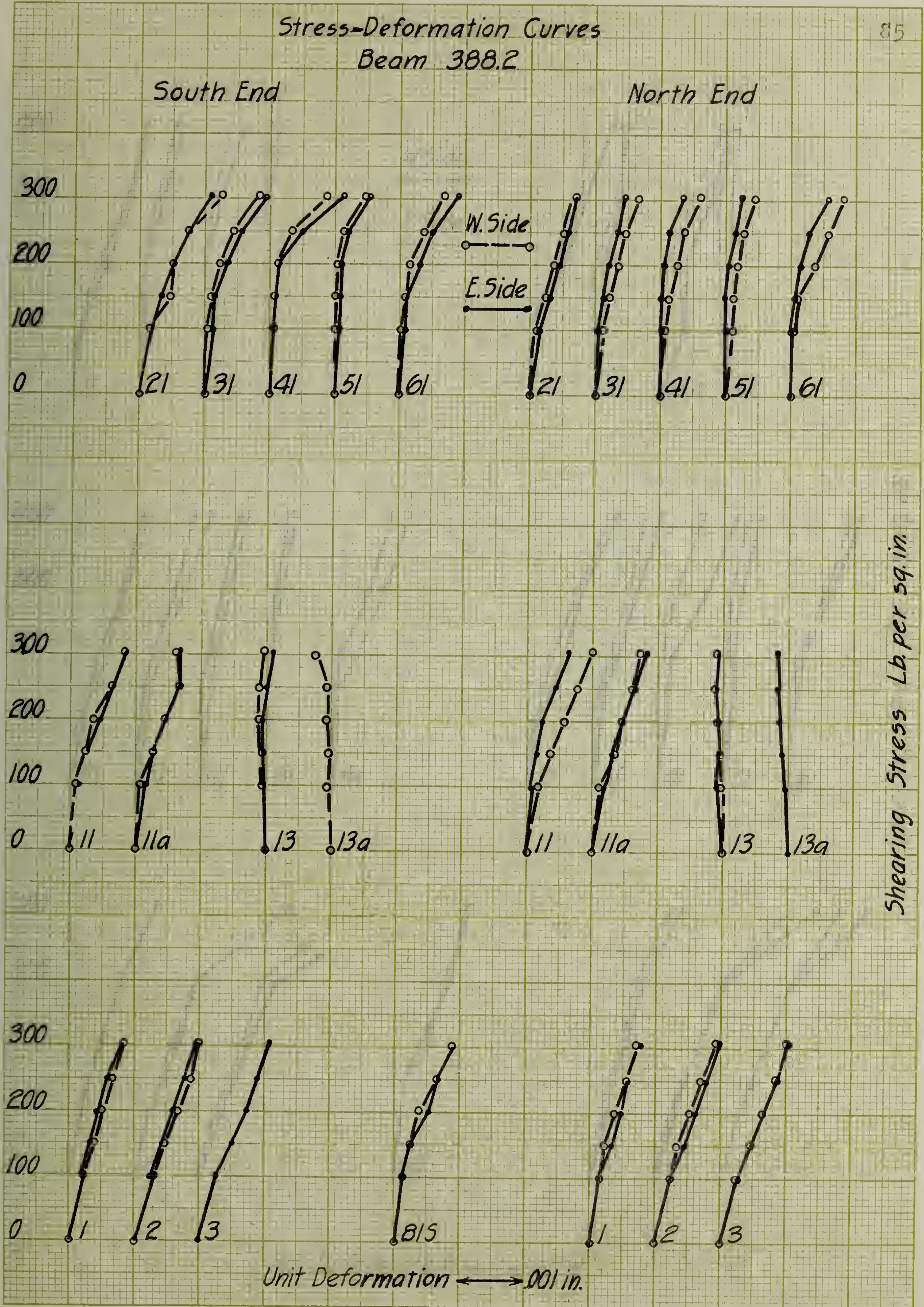



Stress-Deformation Curves
Beam 3871
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.

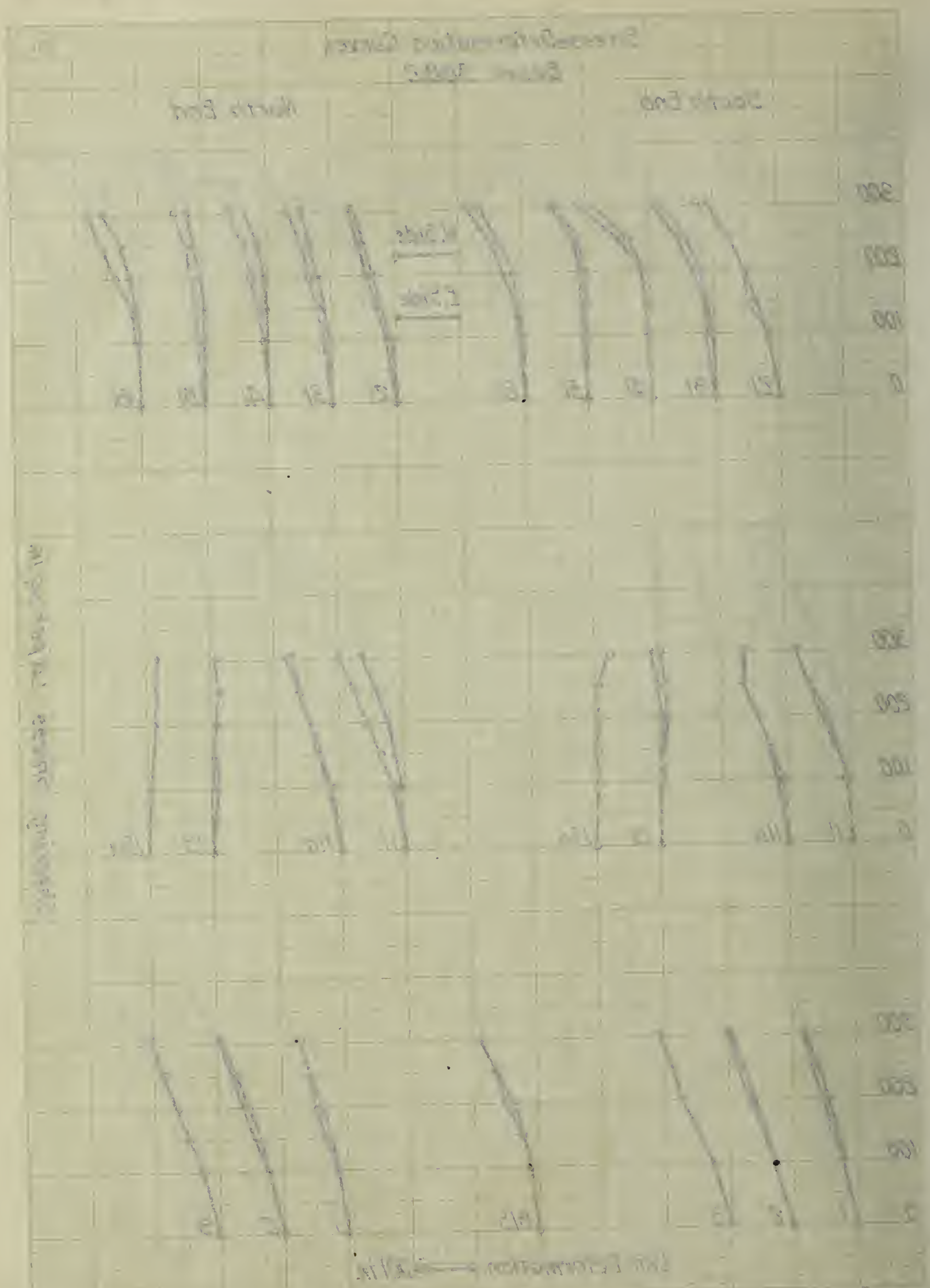

Stress-Deformation Curves
Beam 3872
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
71
22
22a
32
42
52
62
1
2
81
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.

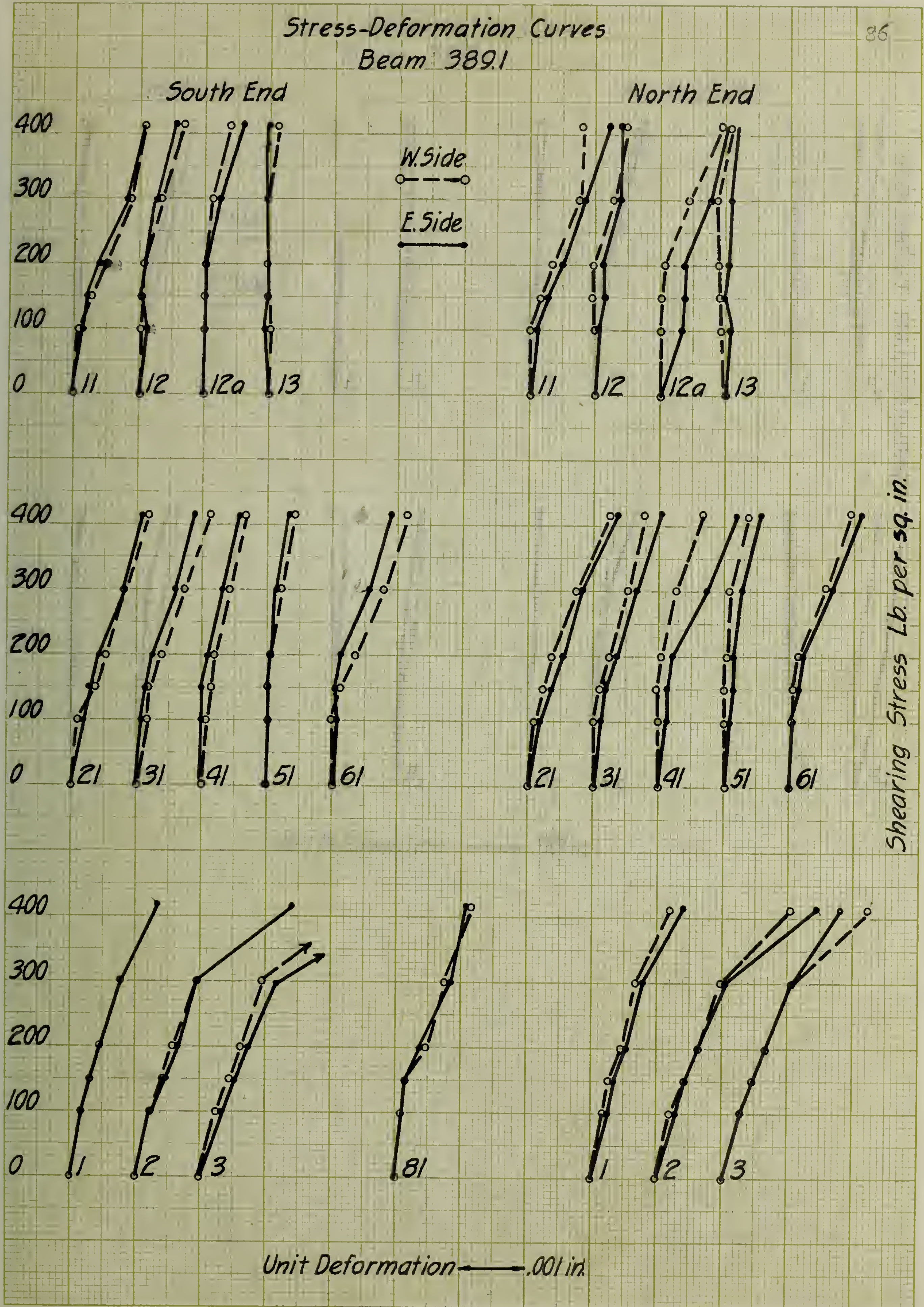


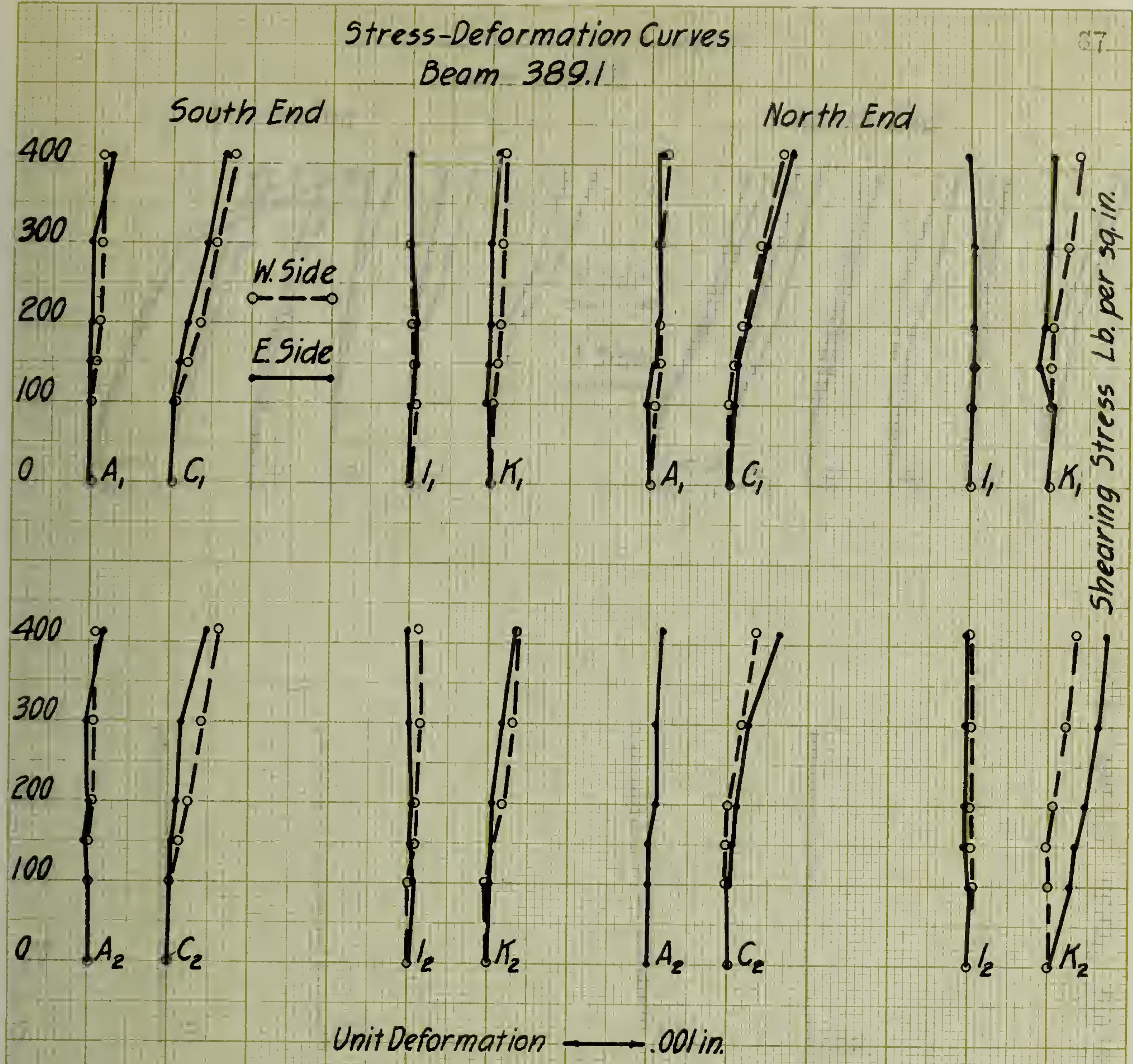
Stress-Deformation Curves
Beam 388.1
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
71
11
12
12a
13
1
2
3
81
Shearing Stress Lb. per sq. in.
Unit Deformation
.001 in



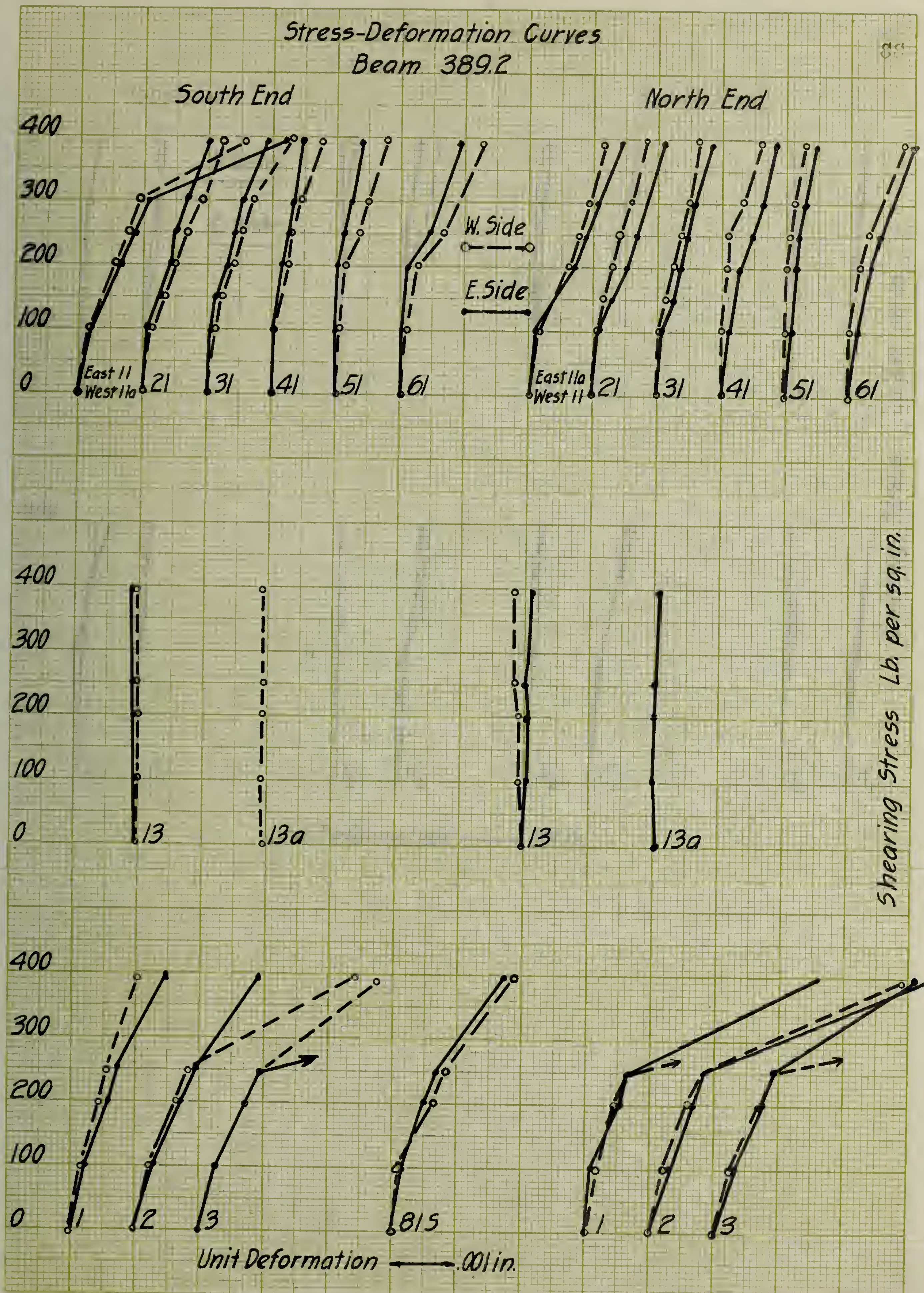
Stress-Deformation Curves
Beam 388.2
South End
North End
W. Side
E. Side
300
200
100
0
21
31
41
51
61
11
11a
13
13a
1
2
3
815
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.



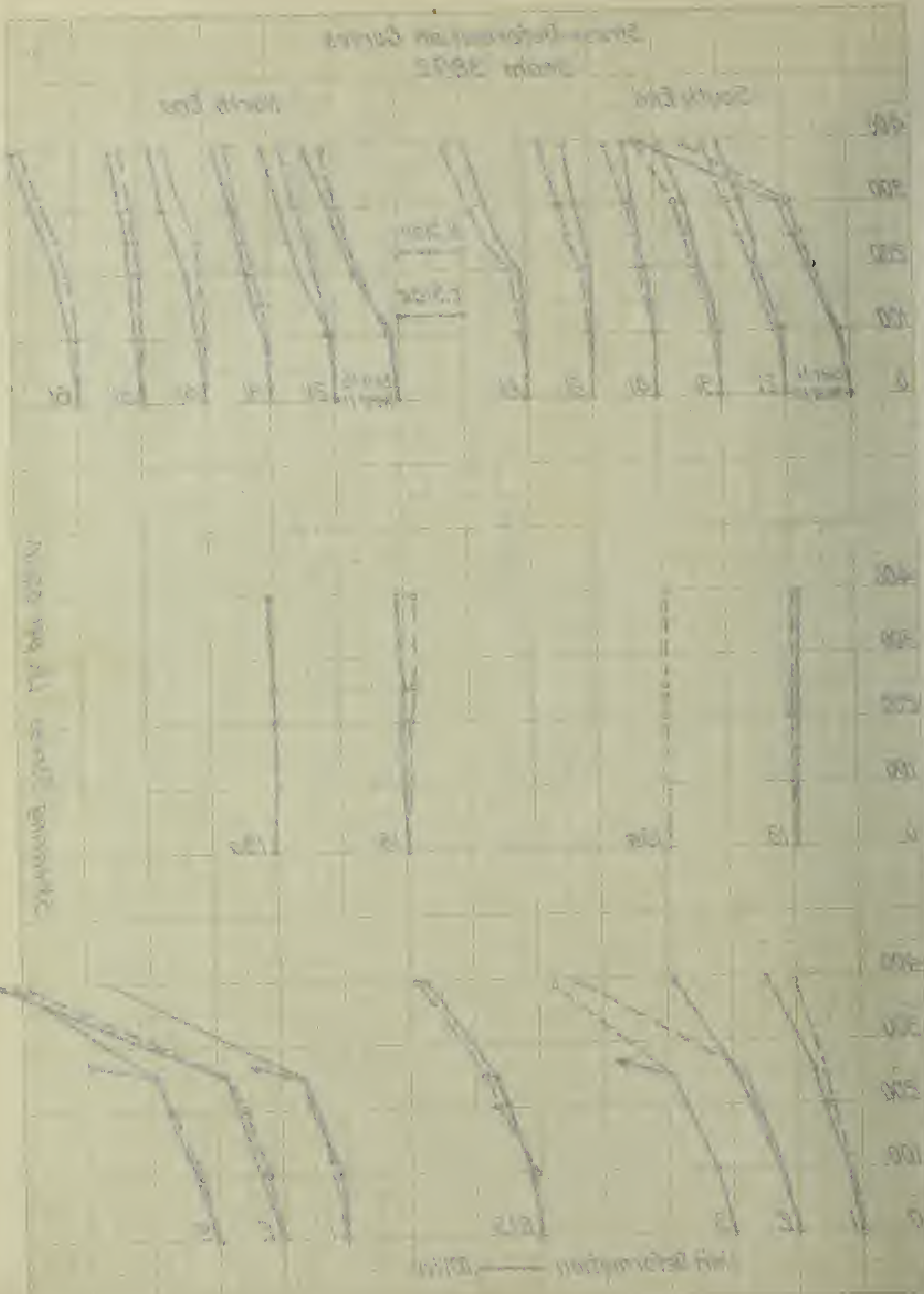

Stress-Deformation Curves
Beam 389.1
South End
North End
W. Side
E. Side
400
300
200
100
0
11
12
12a
13
21
31
41
51
61
1
2
3
81
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.

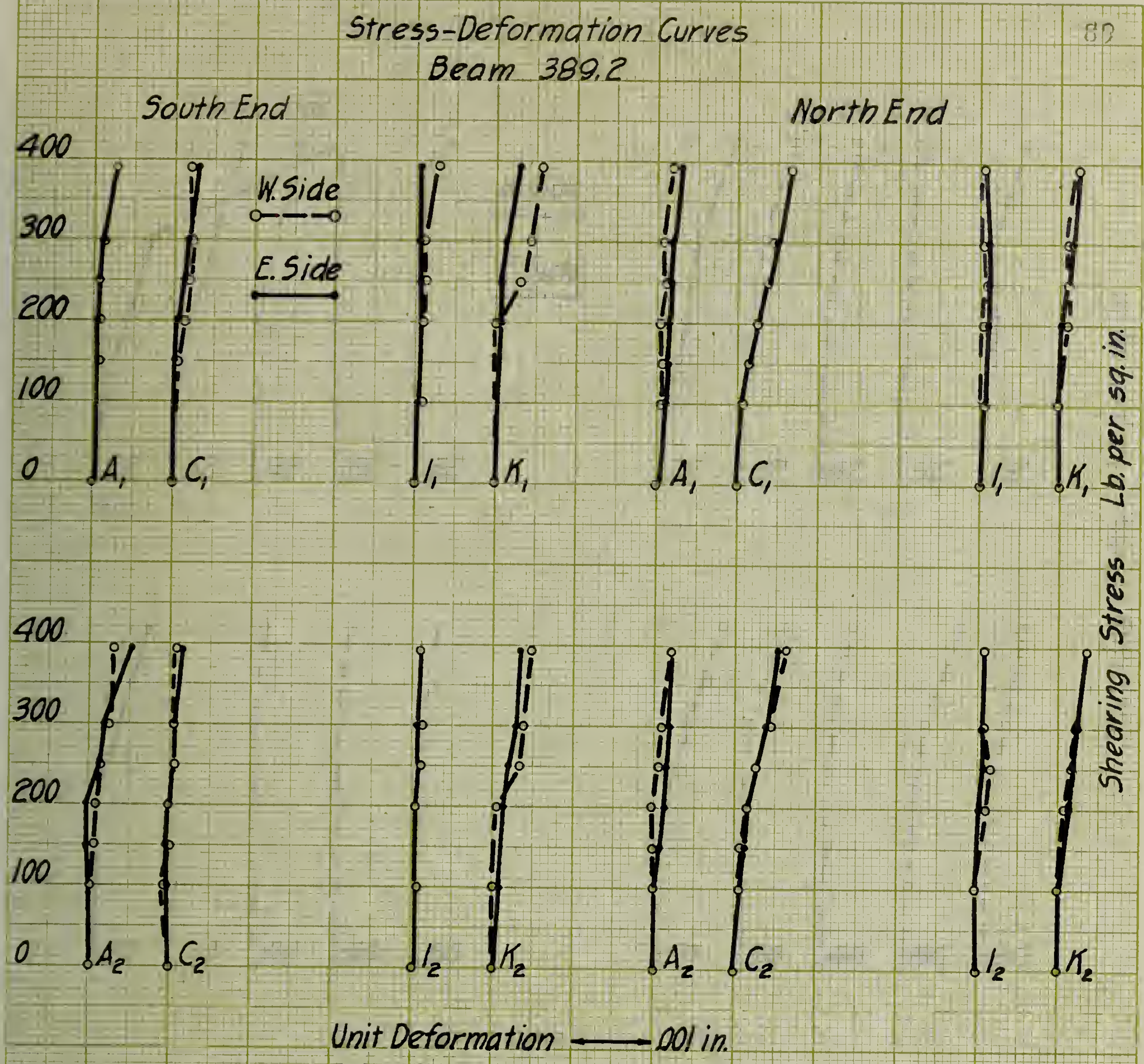


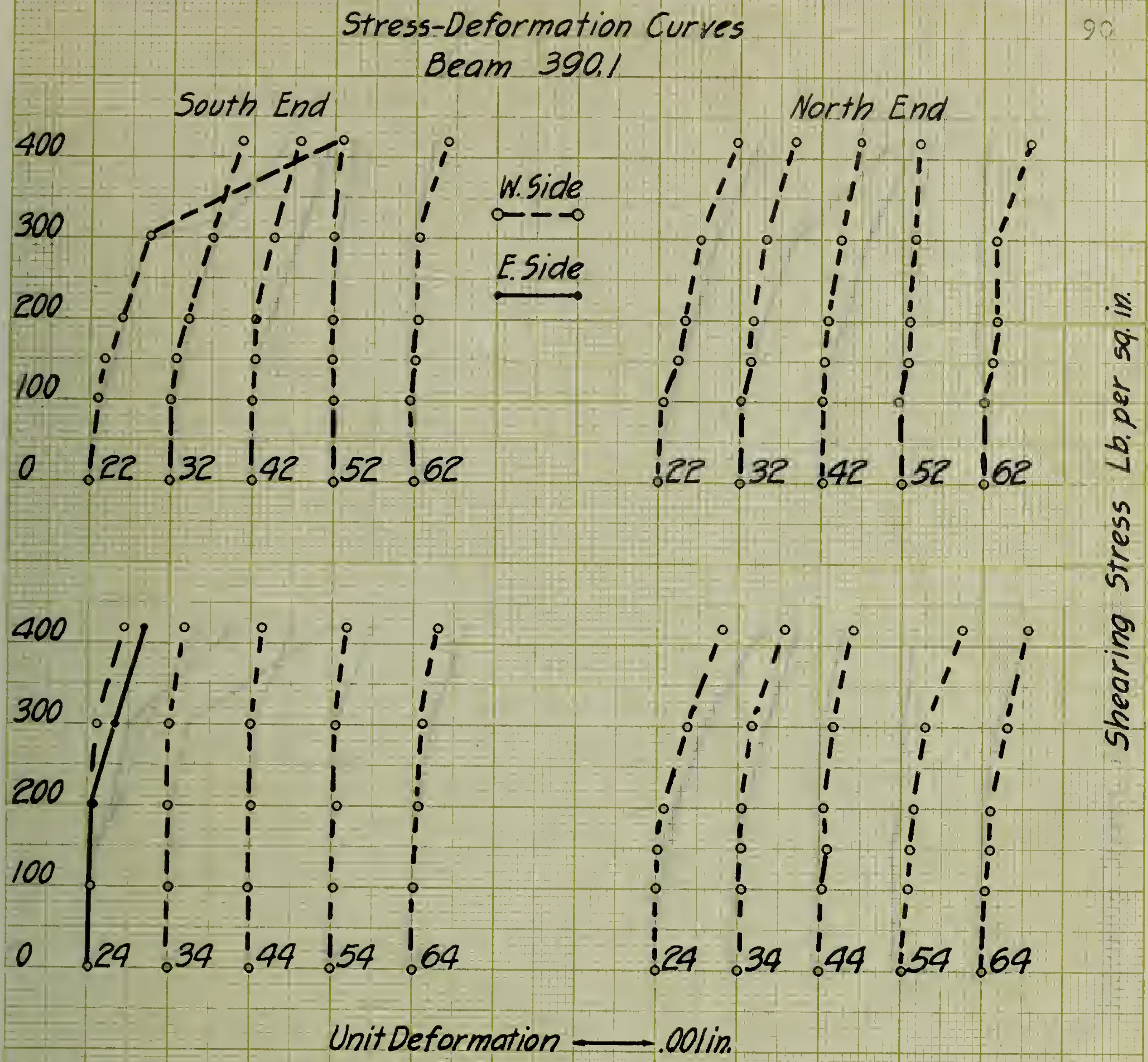
Stress-Deformation Curves
Beam 389.1
South End
North End
W. Side
E. Side
400
300
200
100
0
A₁ C₁ I₁ K₁ A₁ C₁ I₁ K₁
A₂ C₂ I₂ K₂ A₂ C₂ I₂ K₂
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

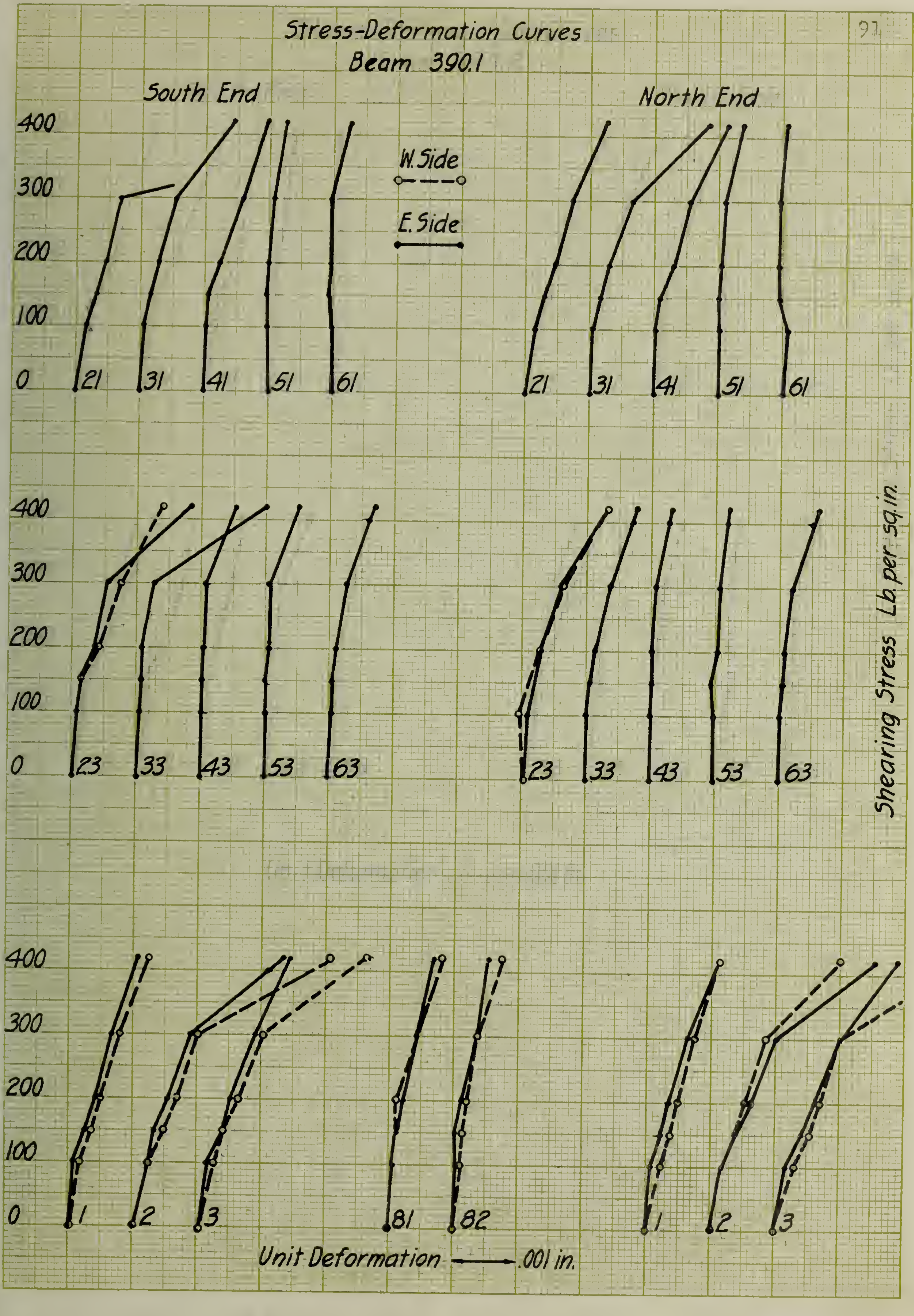


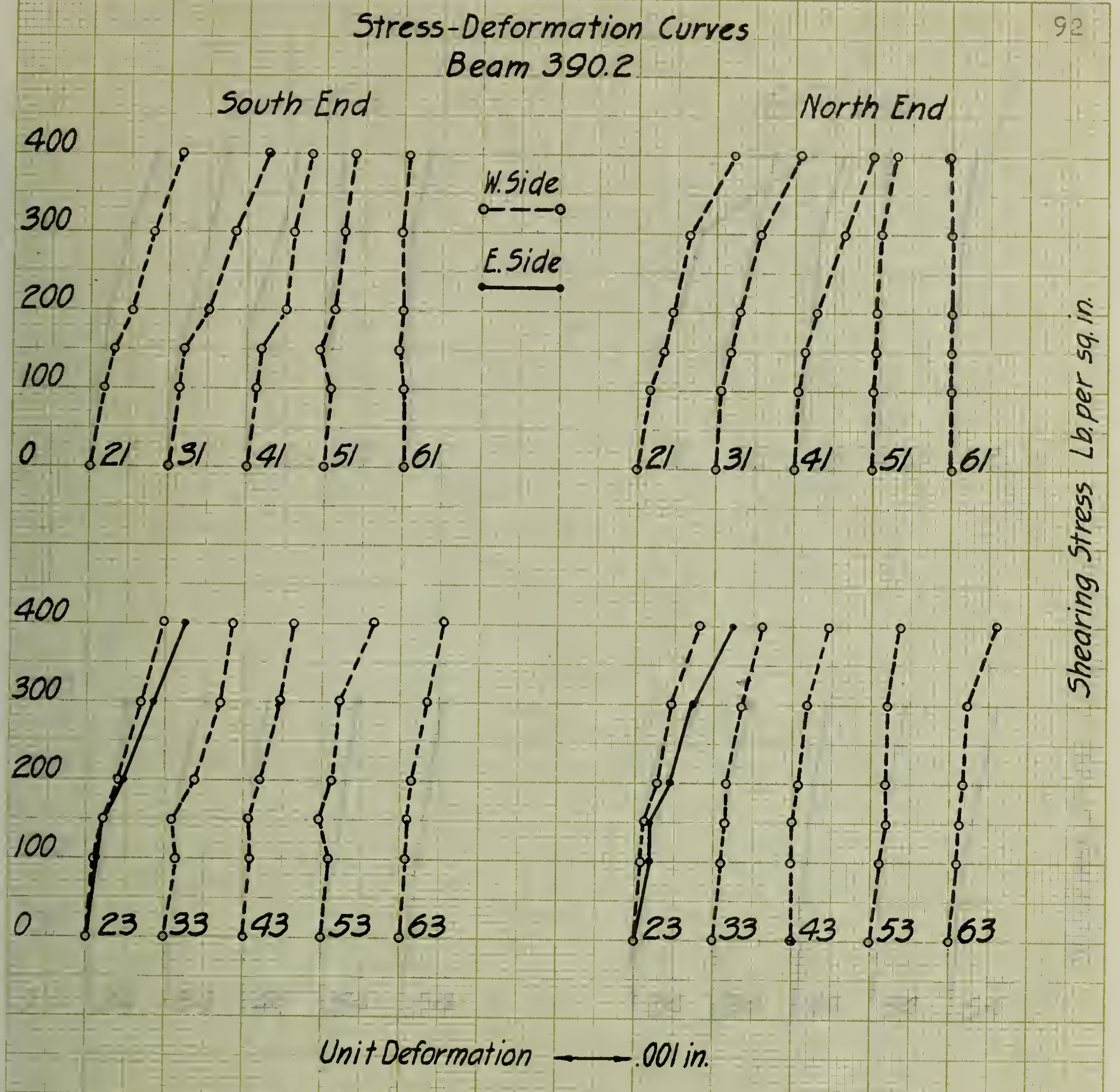
Stress-Deformation Curves
Beam 389.2
South End
North End
W. Side
E. Side
East 11
West 11a
East 11a
West 11
21
31
41
51
61
13
13a
1
2
3
815
0
100
200
300
400
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.




Stress-Deformation Curves
Beam 389.2
South End
North End
W. Side
E. Side
400
300
200
100
0
A1
C1
I1
K1
A2
C2
I2
K2
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.


Stress-Deformation Curves
Beam 390.1
South End
North End
W. Side
E. Side
400
300
200
100
0
22
32
42
52
62
29
34
44
54
64
24
Shearing Stress Lb. per sq. in.
Unit Deformation ⟵⟶ .001 in.


Stress-Deformation Curves
Beam 390.1
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
23
33
43
53
63
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation —— .001 in.


Stress-Deformation Curves
Beam 390.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21
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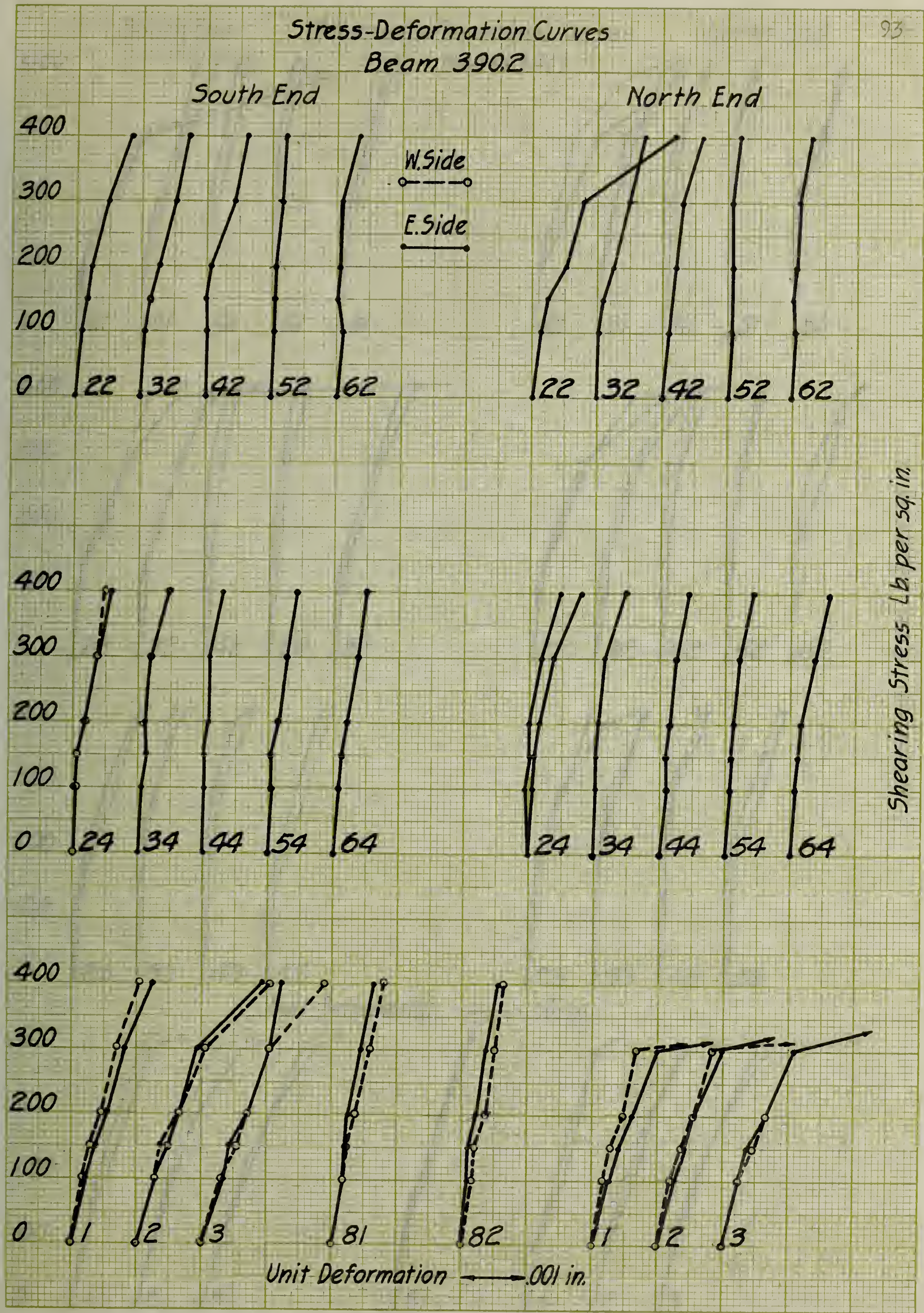
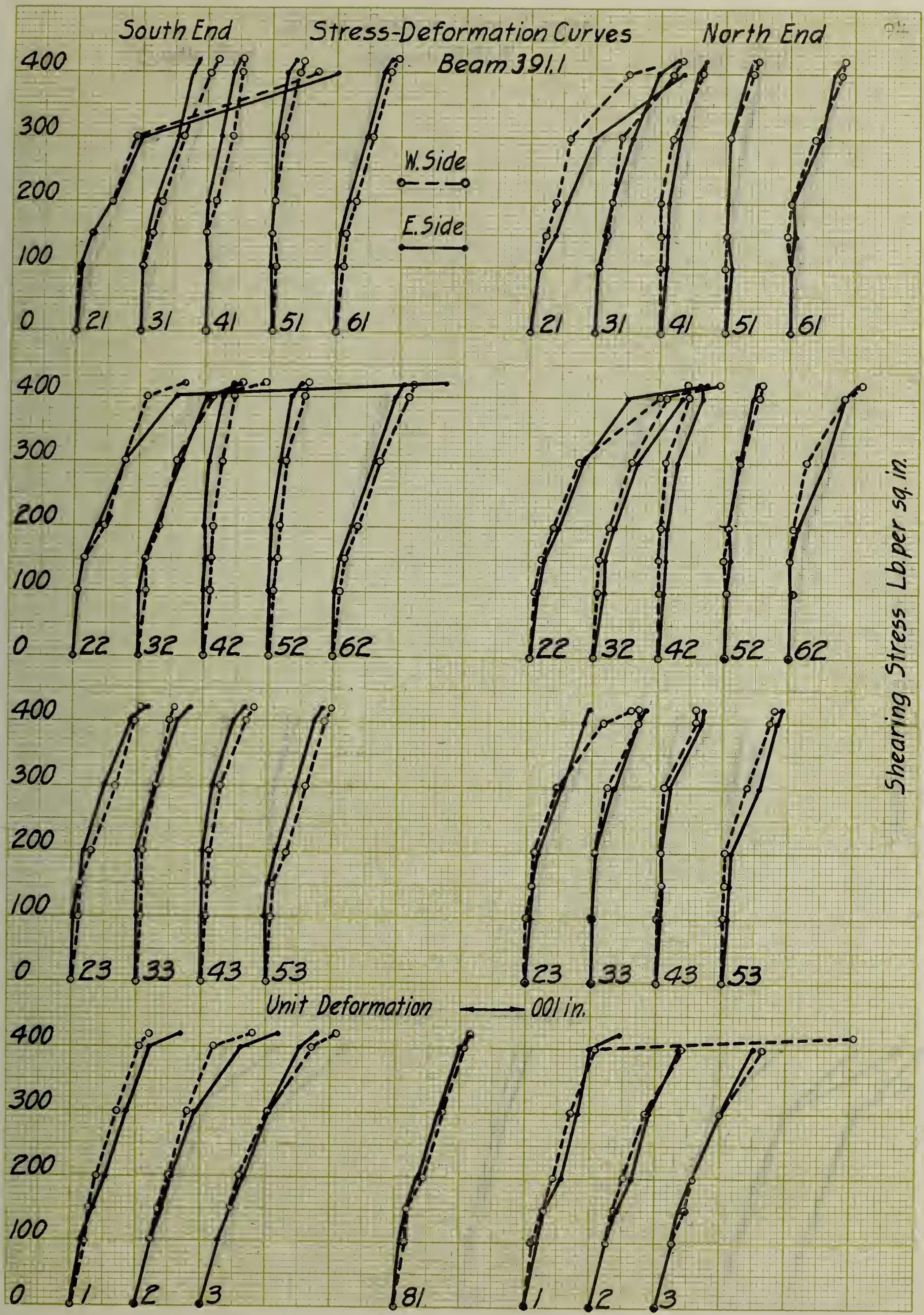
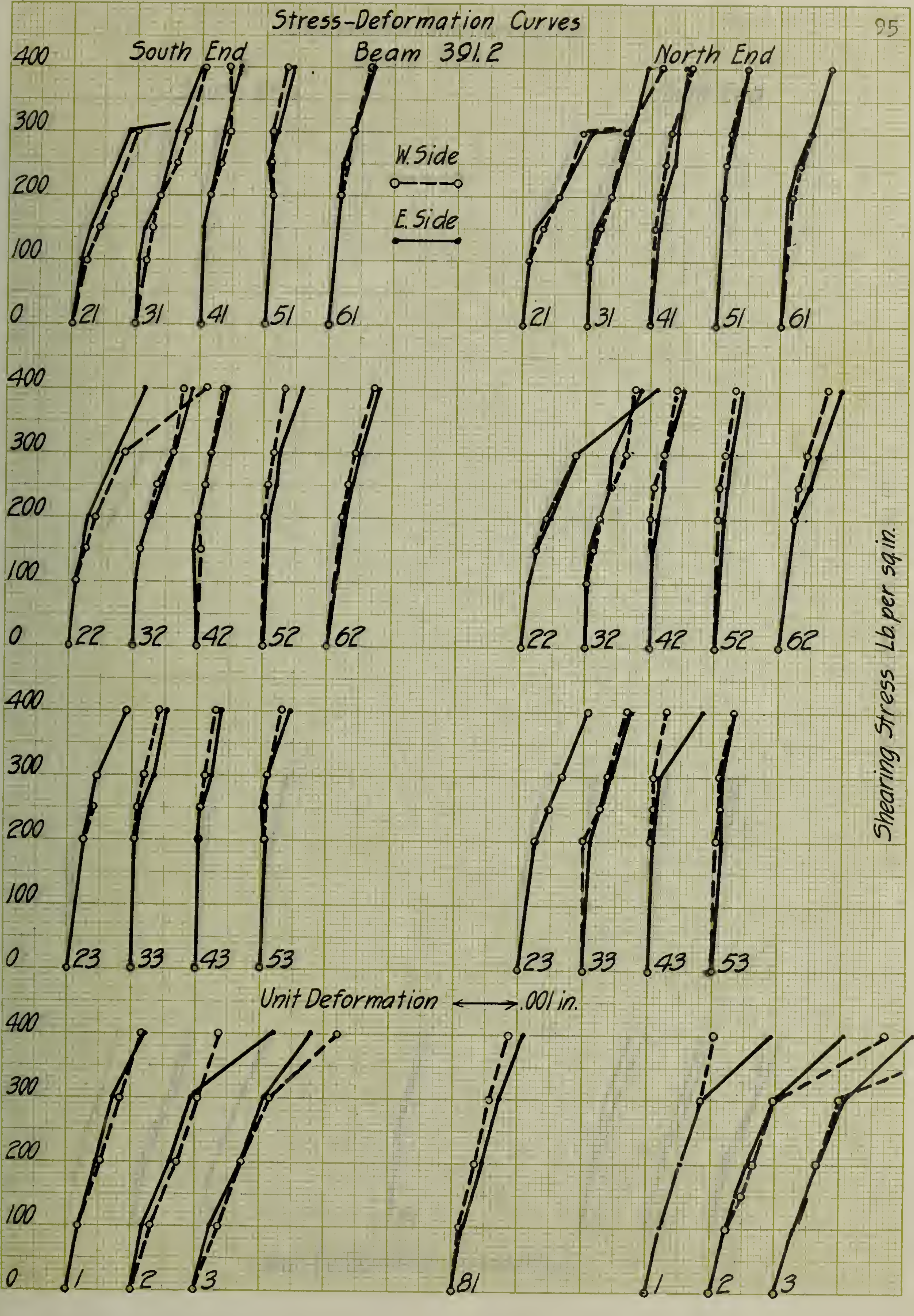
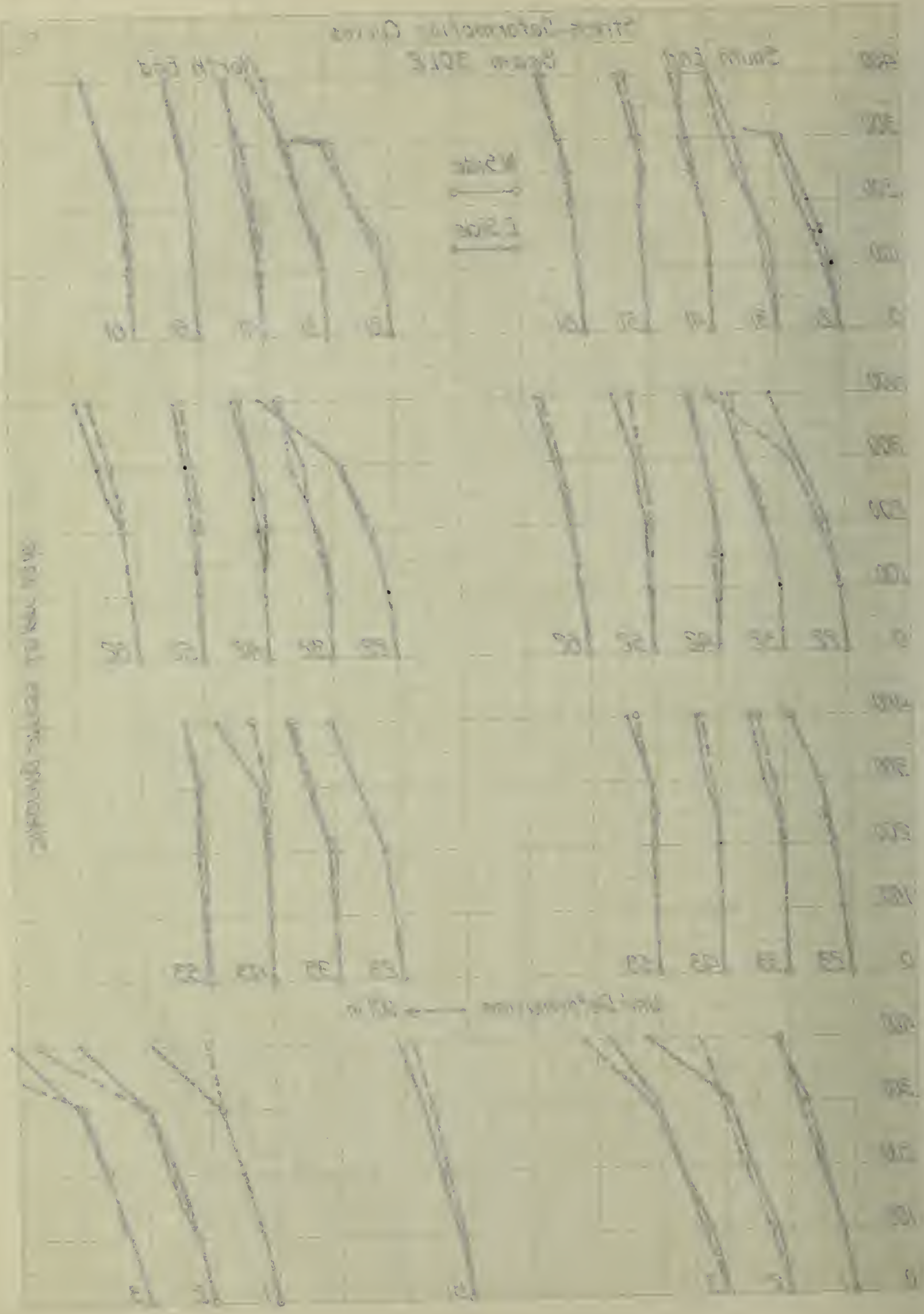
41
51
61
23
33
43
53
63
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

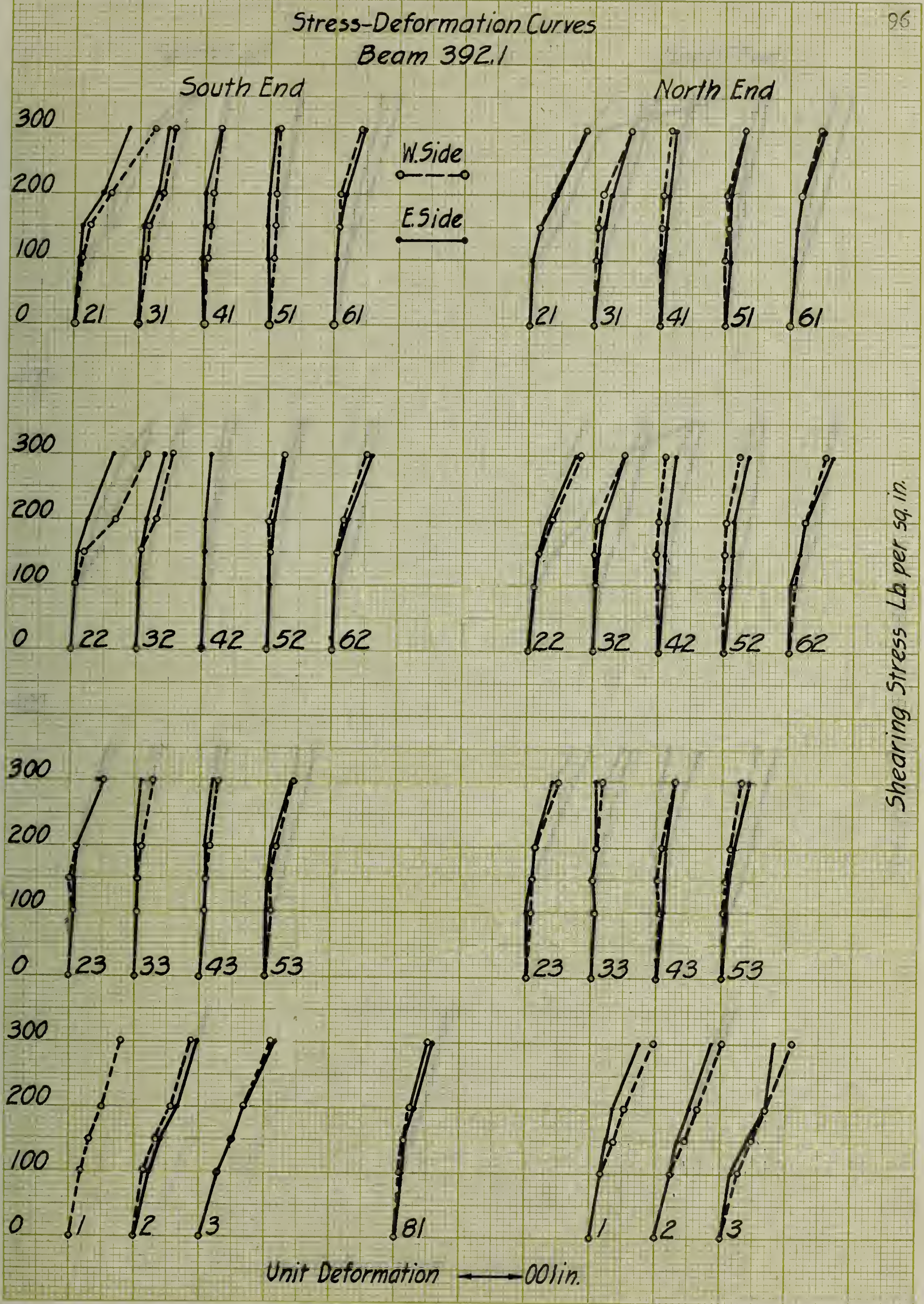

Stress-Deformation Curves
Beam 390.2
South End
North End
W. Side
E. Side
400
300
200
100
0
22
32
42
52
62
24
34
44
54
64
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.

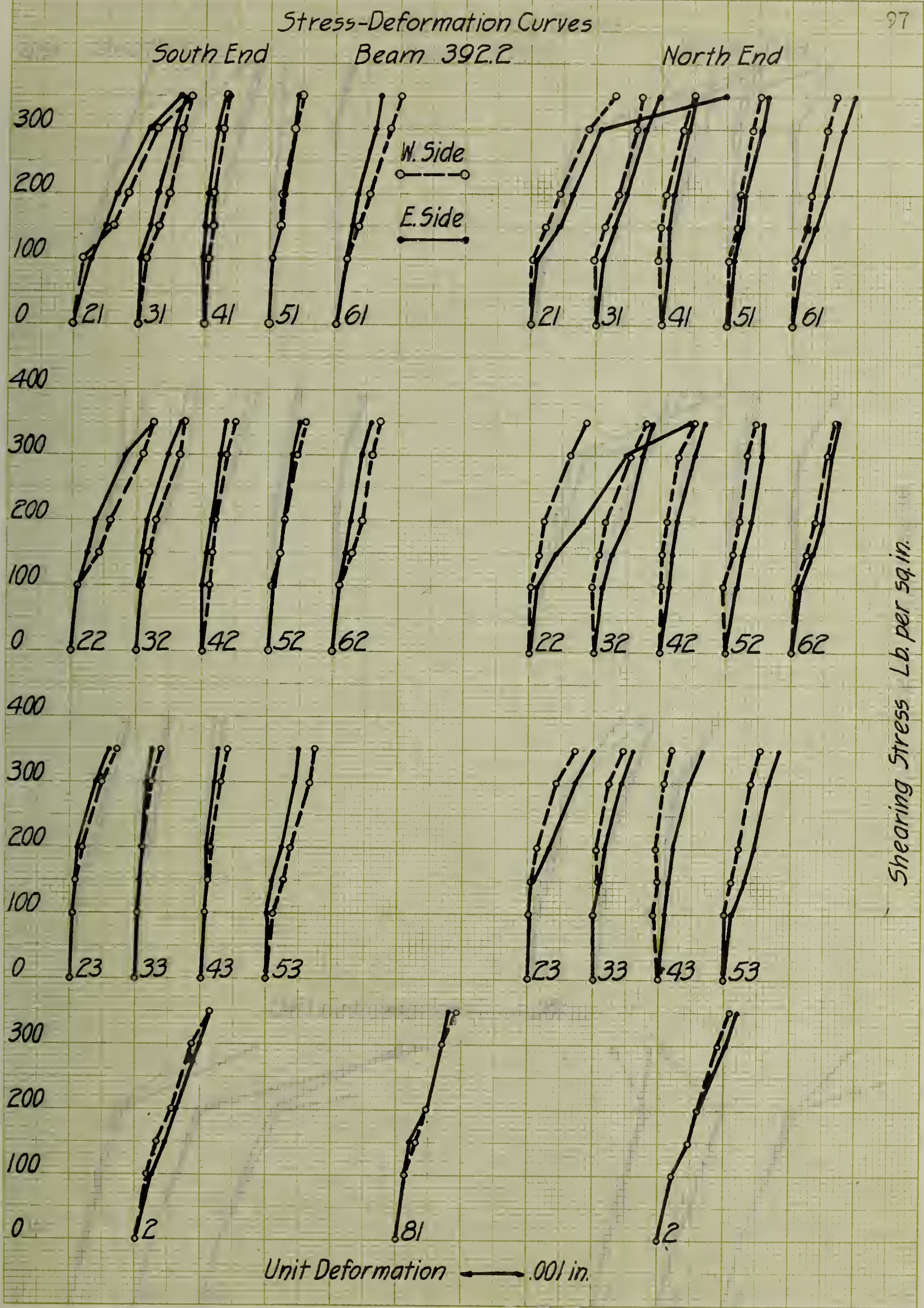


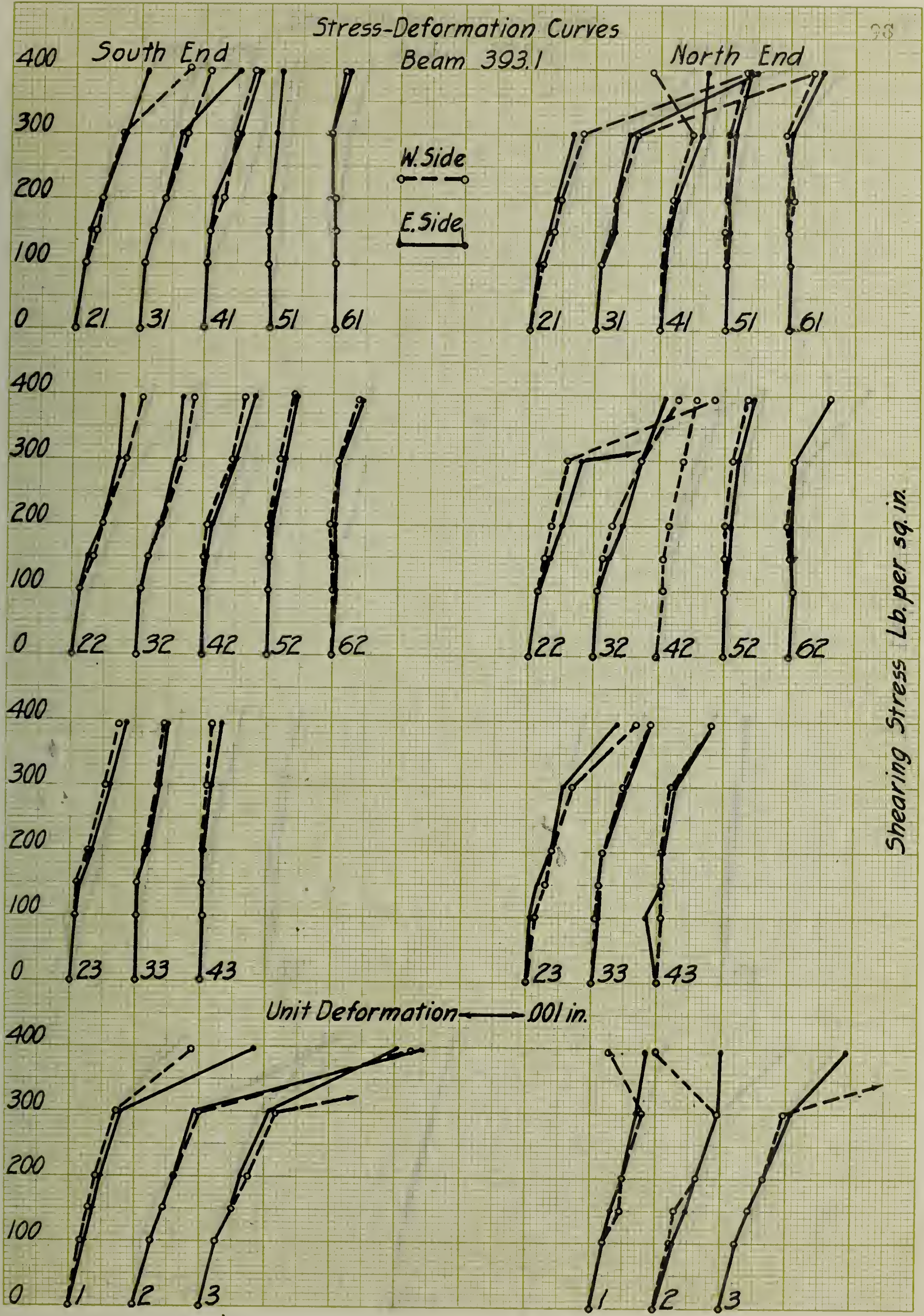
South End
Stress-Deformation Curves
Beam 391.1
North End
W. Side
E. Side
Shearing Stress Lb. per sq. in.
Unit Deformation ← → .001 in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
1
2
3
81


Stress-Deformation Curves
Beam 391.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21 31 41 51 61
22 32 42 52 62
23 33 43 53
1 2 3
81
Unit Deformation ⟷ .001 in.
Shearing Stress Lb. per sq. in.

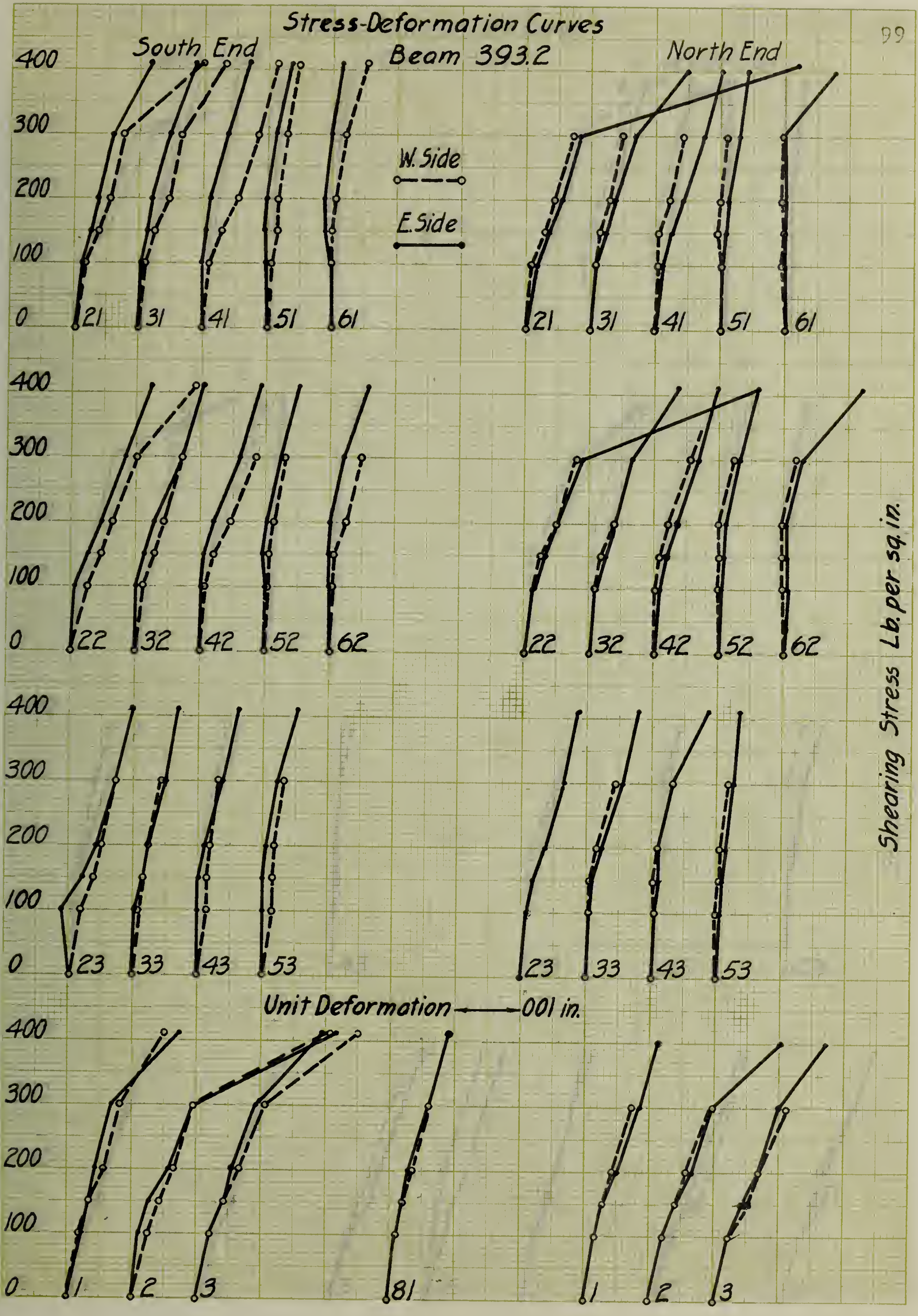



Stress-Deformation Curves
Beam 392.1
South End
North End
W. Side
E. Side
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
1
2
3
81
Shearing Stress Lb per sq. in.
Unit Deformation .001 in.

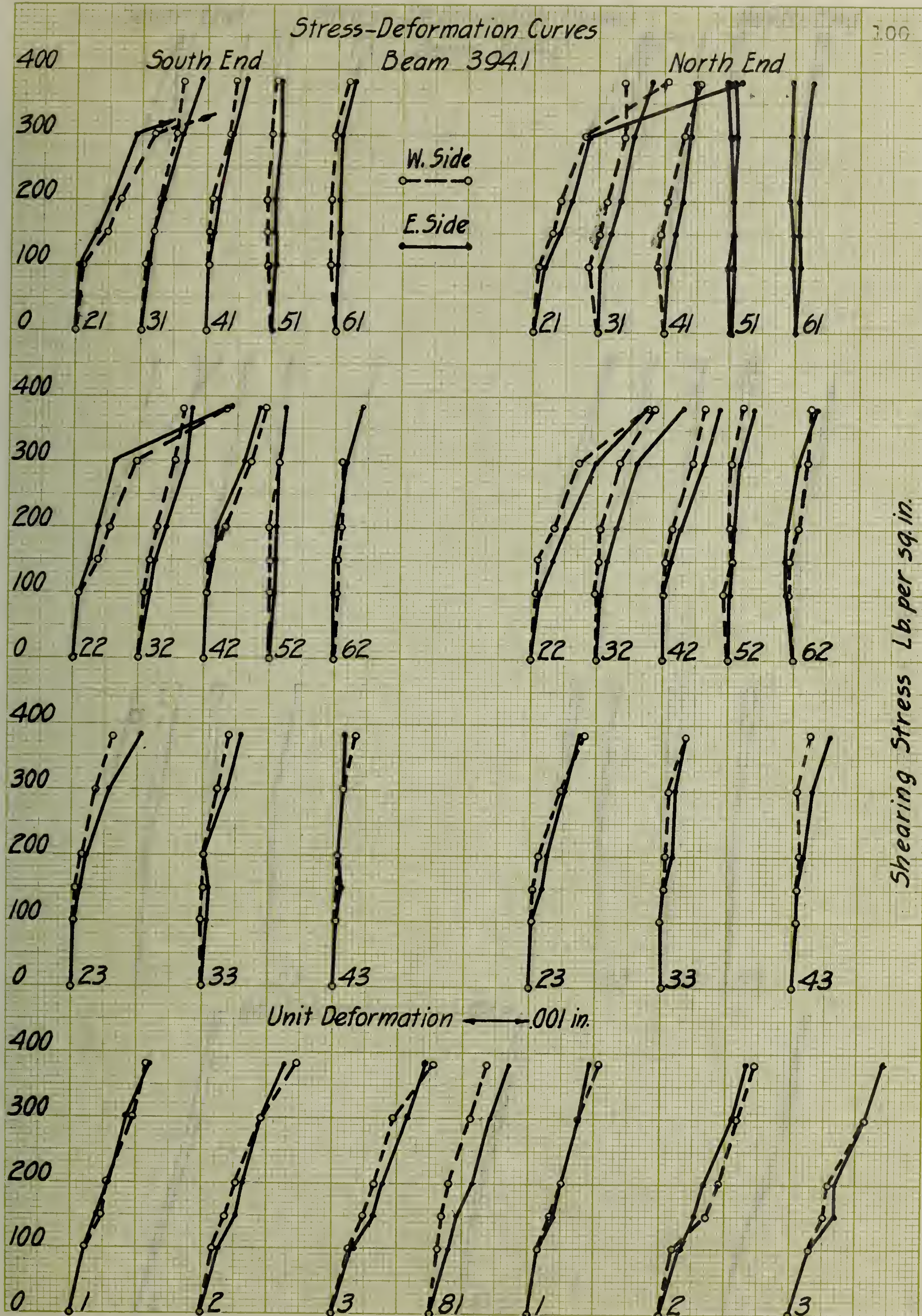

Stress-Deformation Curves
South End
Beam 392.2
North End
W. Side
E. Side
300
200
100
0
400
21
31
41
51
61
22
32
42
52
62
23
33
43
53
2
81
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.



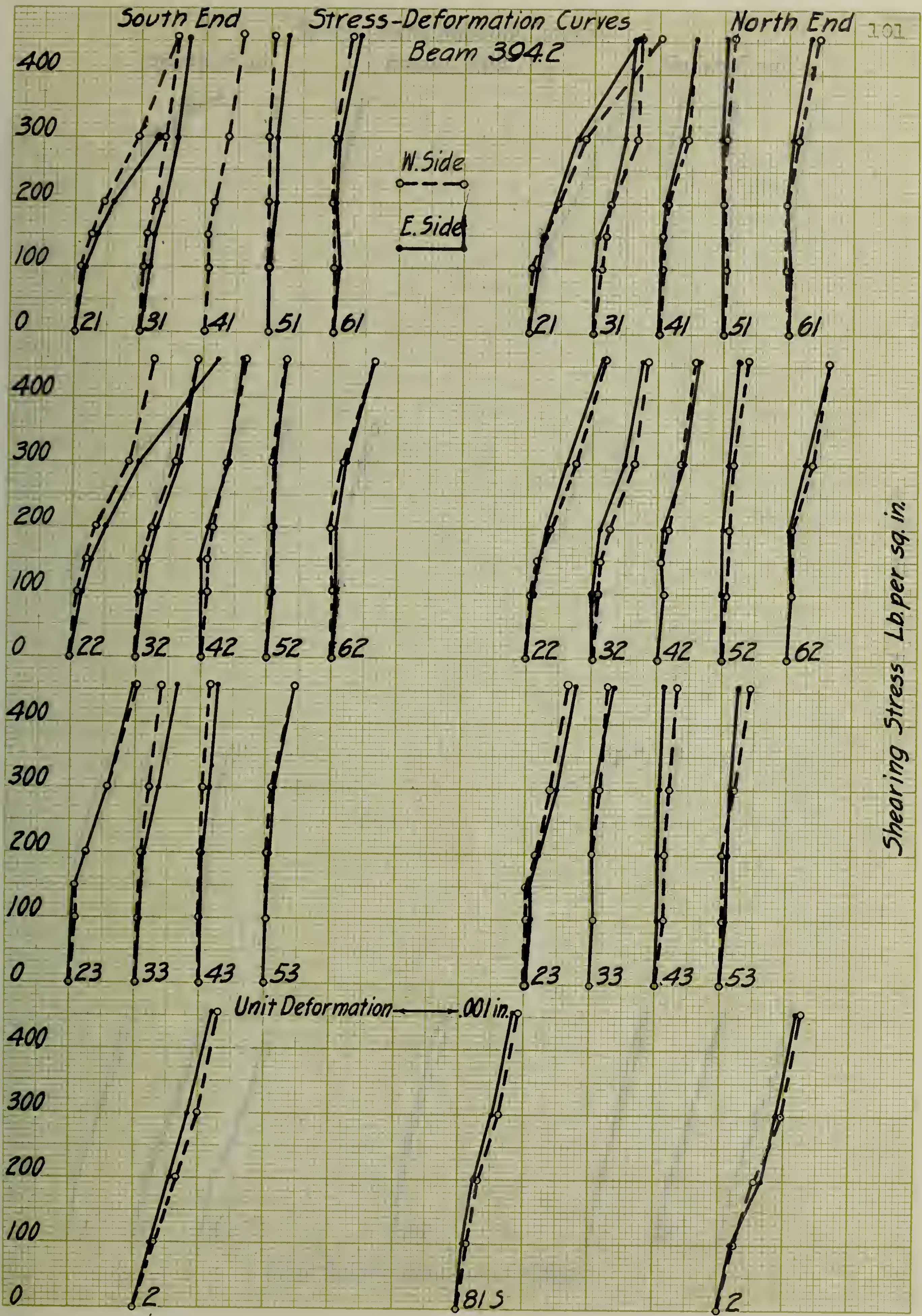
Stress-Deformation Curves
Beam 393.1
South End
North End
W. Side
E. Side
Unit Deformation ←→ .001 in.
Shearing Stress Lb. per sq. in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
1
2
3

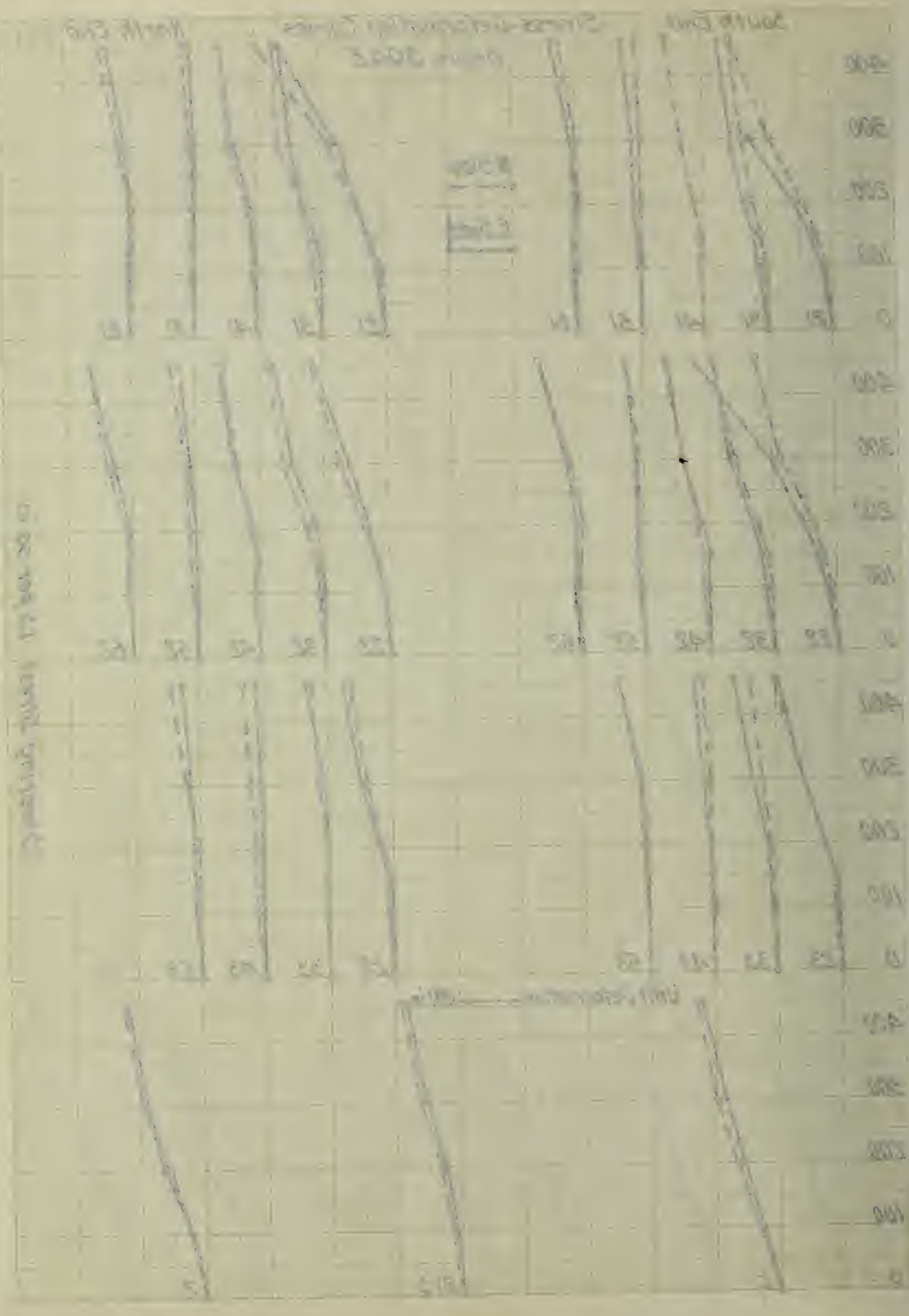


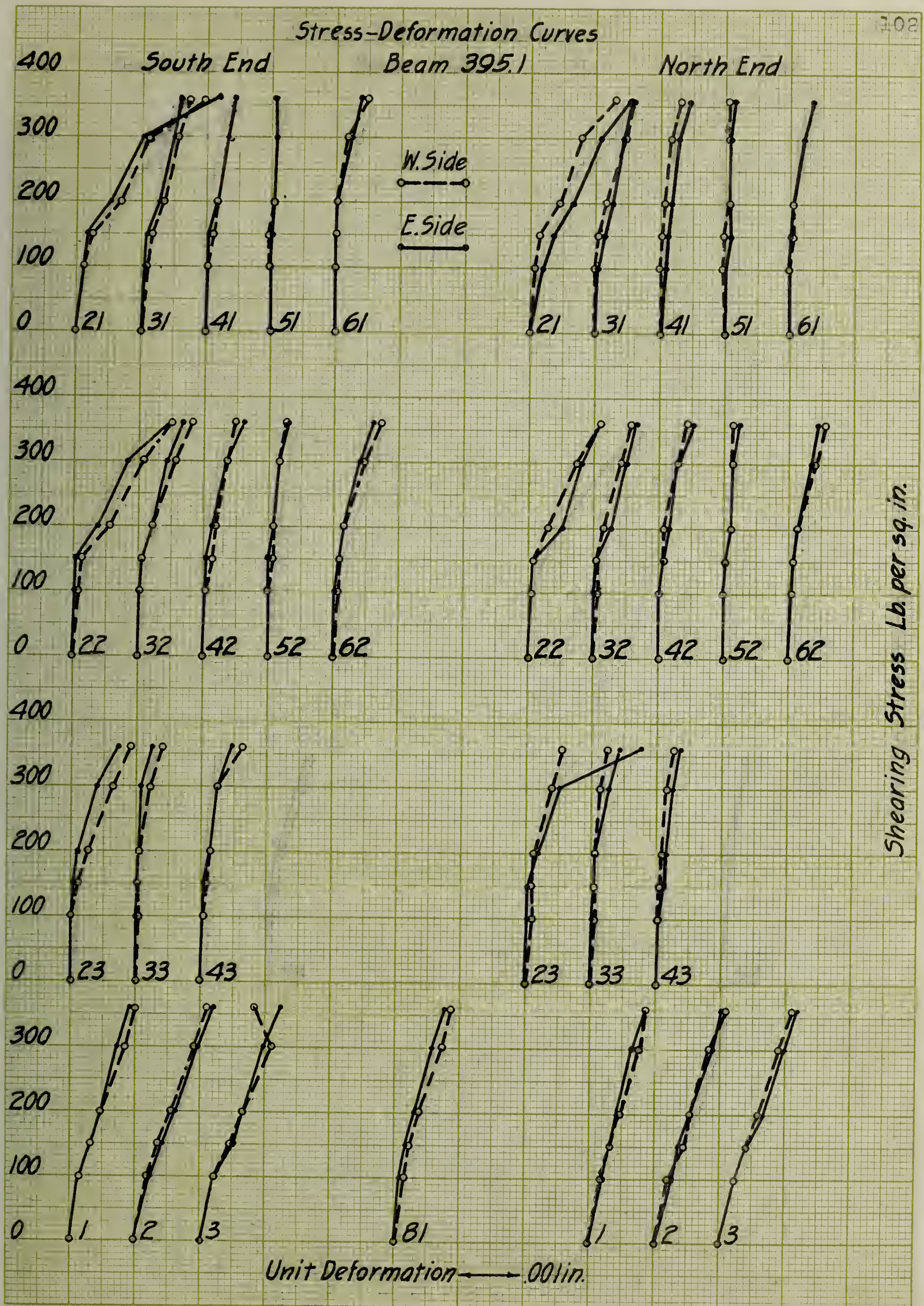
Stress-Deformation Curves
Beam 393.2
South End
North End
W. Side
E. Side
Unit Deformation ——— .001 in.
Shearing Stress Lb. per sq. in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
1
2
3
81



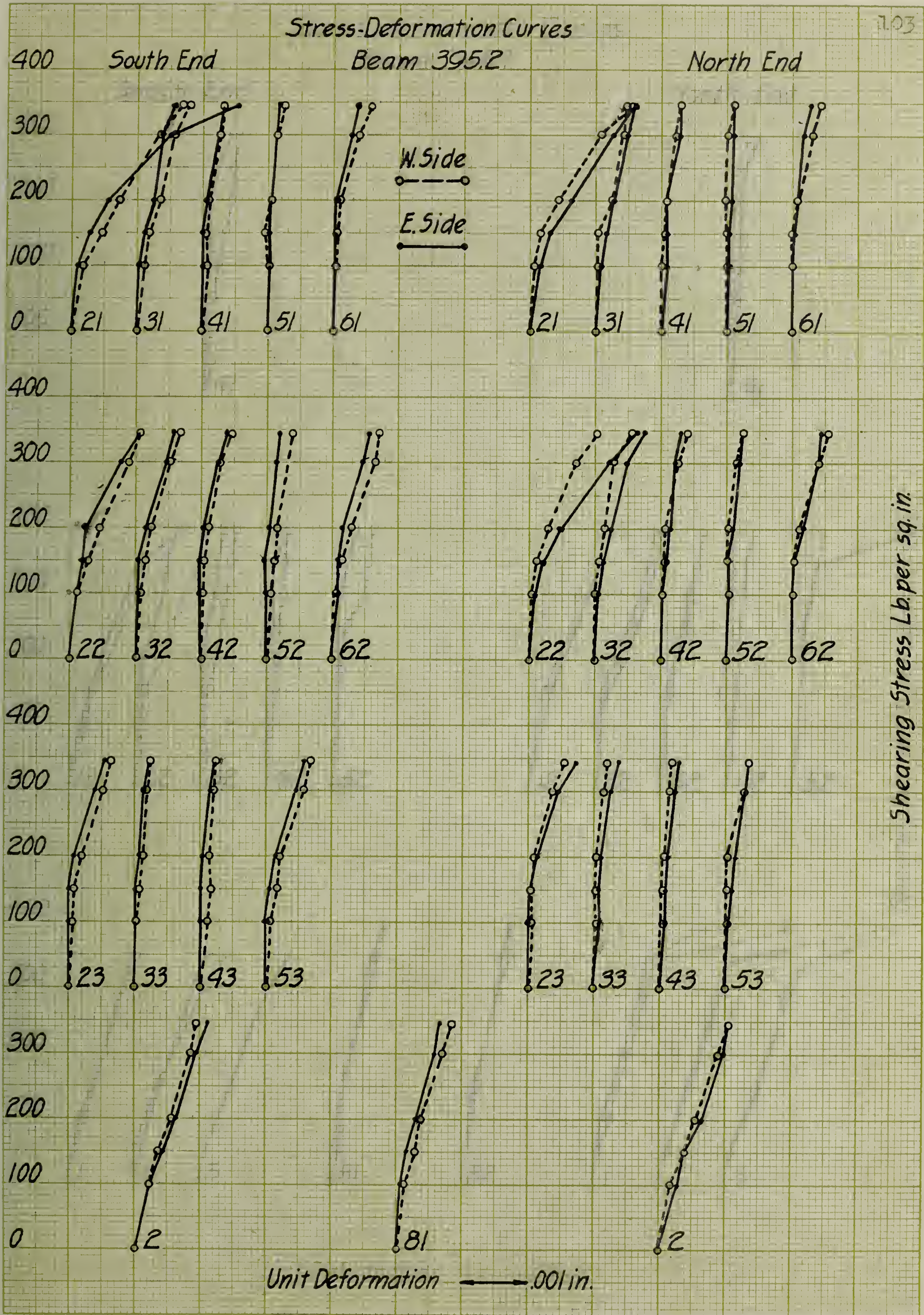
Stress-Deformation Curves
Beam 394.1
South End
North End
W. Side
E. Side
Shearing Stress Lb. per sq. in.
Unit Deformation ⟷ .001 in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
1
2
3
81

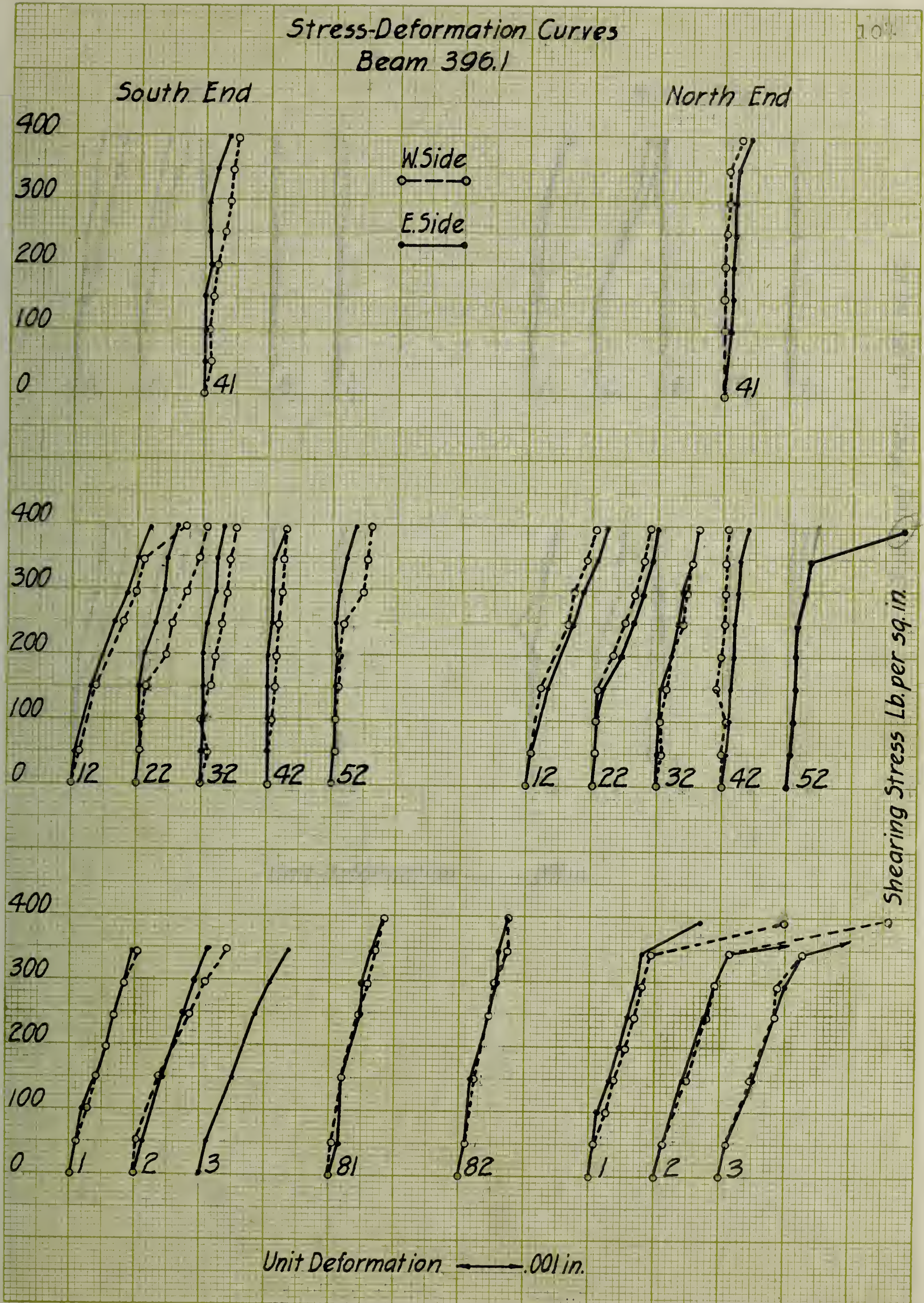

South End
Stress-Deformation Curves
Beam 394.2
North End
W. Side
E. Side
Shearing Stress Lb. per sq. in.
Unit Deformation ←—→ .001 in.
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
2
81 S

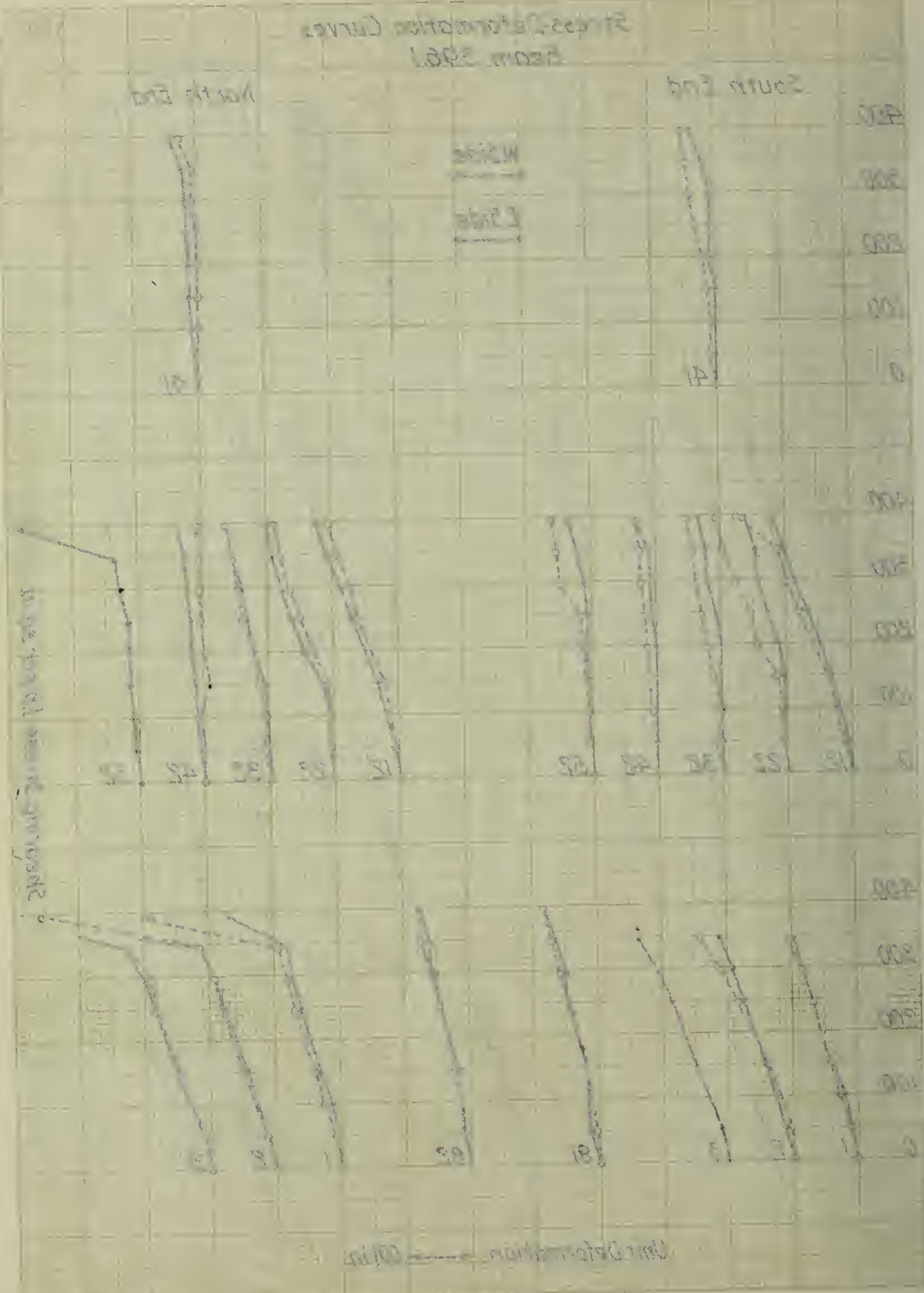


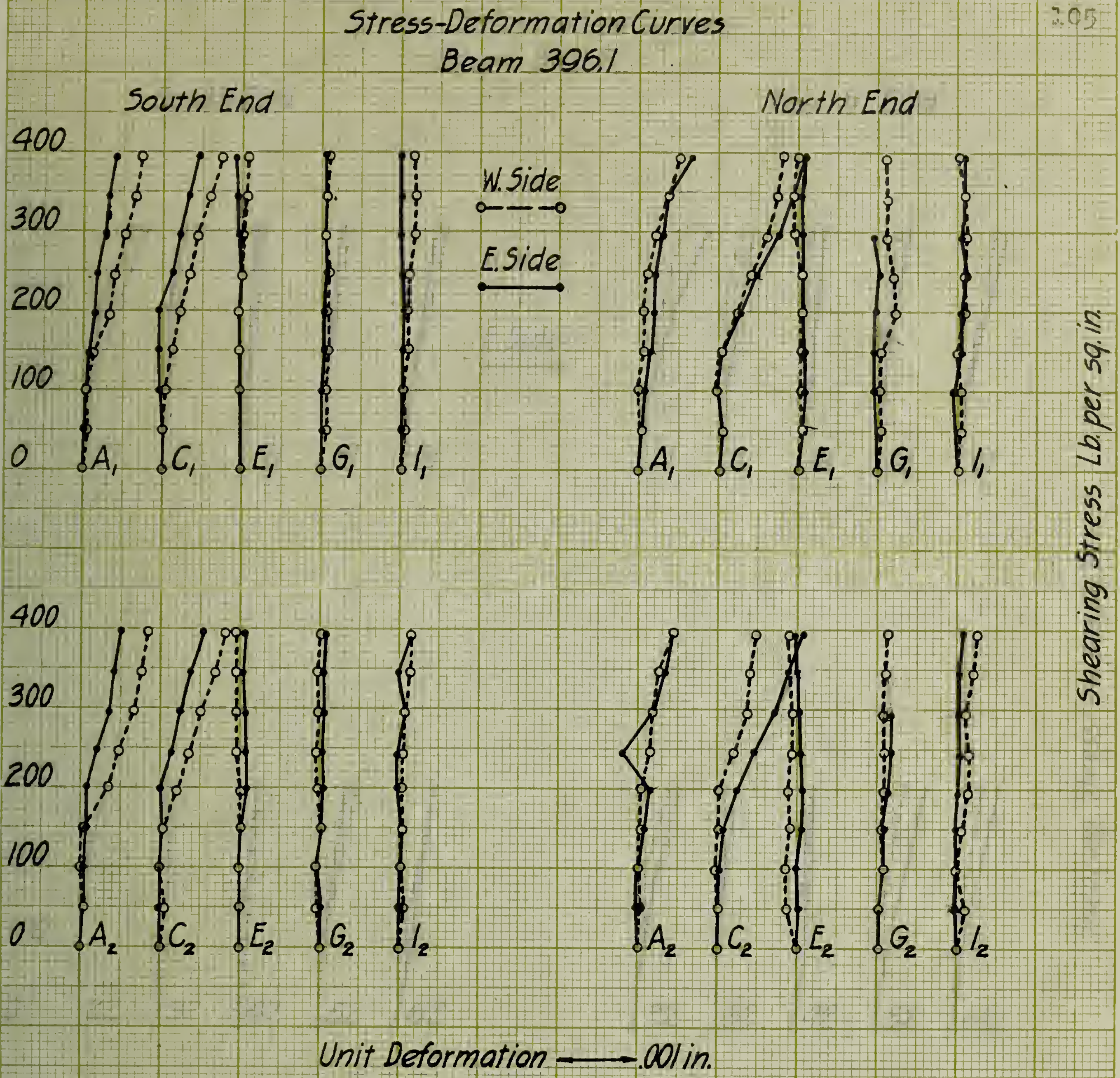


102
Stress-Deformation Curves
Beam 395.1
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
1
2
3
81
Shearing Stress Lb. per sq. in.
Unit Deformation ⟶ .001 in.

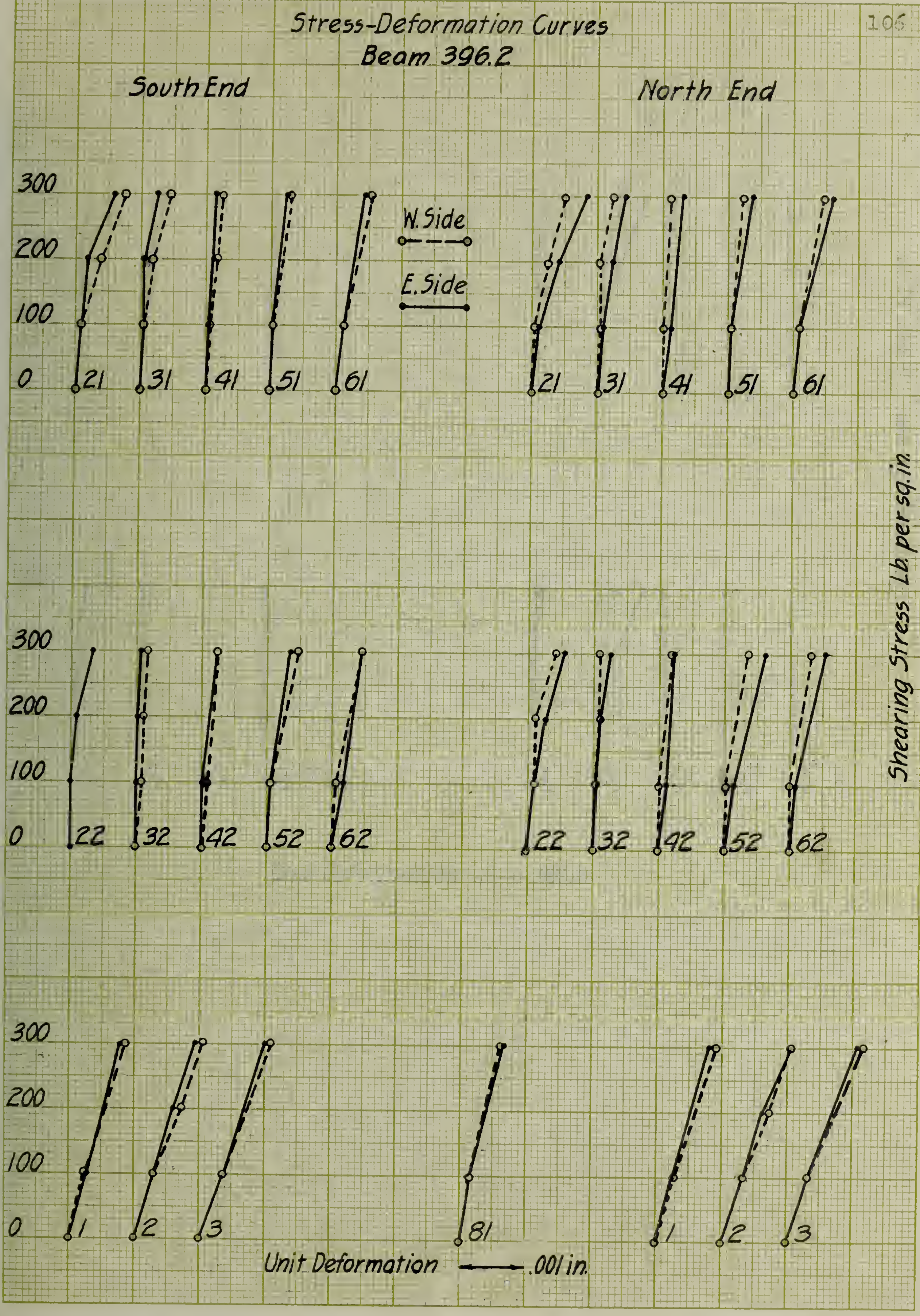

Stress-Deformation Curves
Beam 395.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
23
33
43
53
2
81
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.

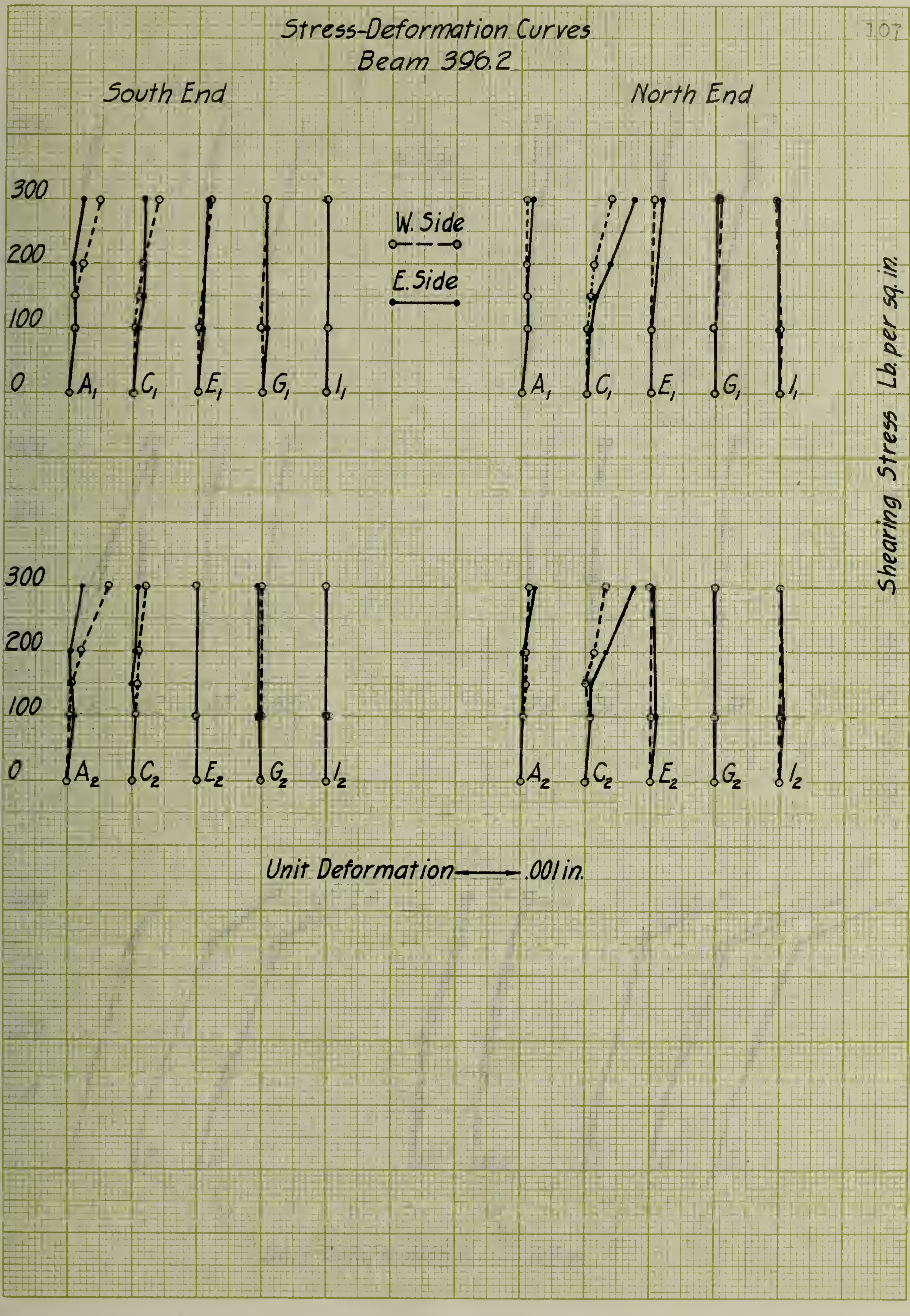

Stress-Deformation Curves
Beam 396.1
South End
North End
W.Side
E.Side
400
300
200
100
0
41
41
12
22
32
42
52
12
22
32
42
52
1
2
3
81
82
1
2
3
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

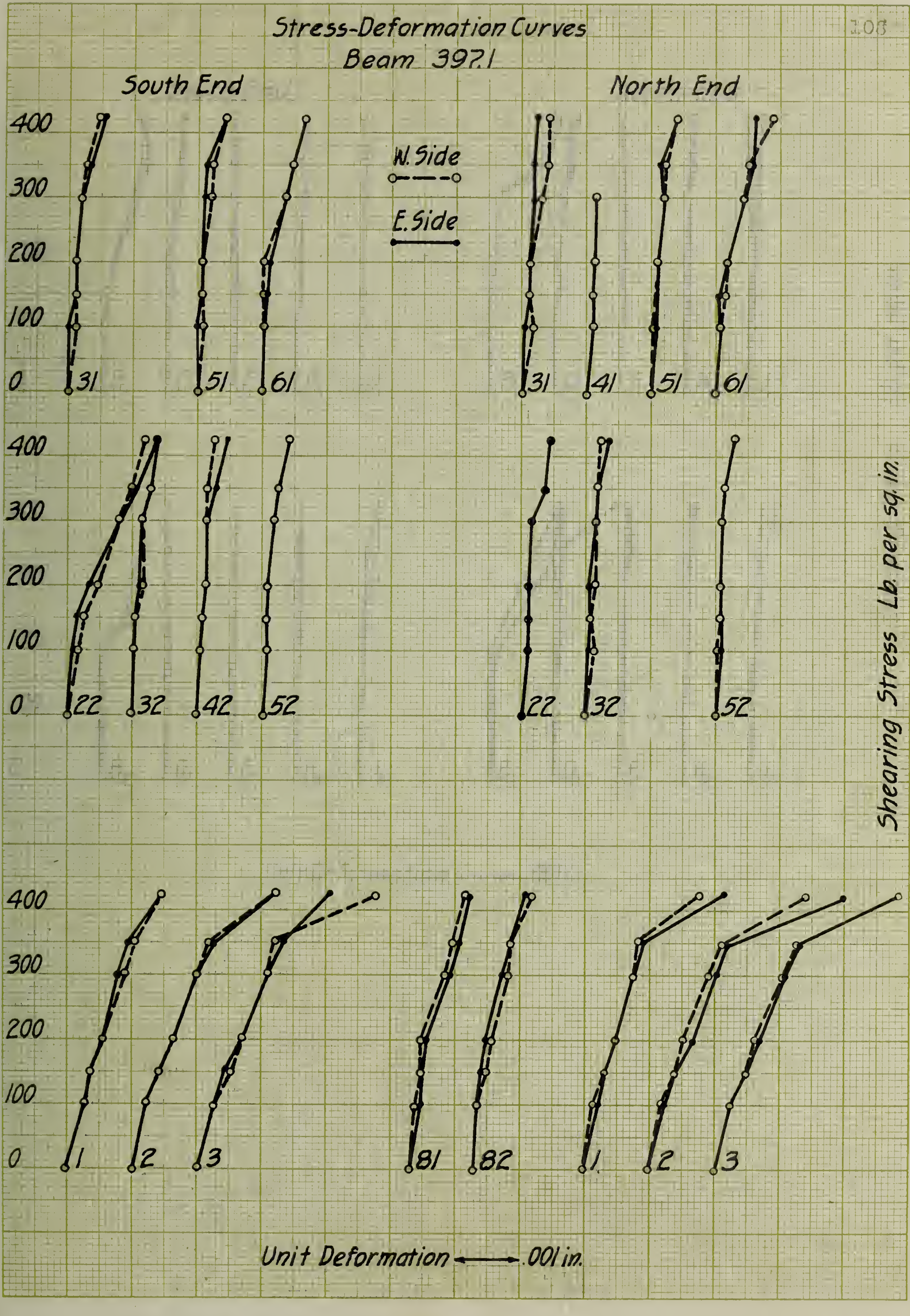

Stress-Deformation Curves
Beam 396.1
North End
South End
W. Side
E. Side
Unit Deformation



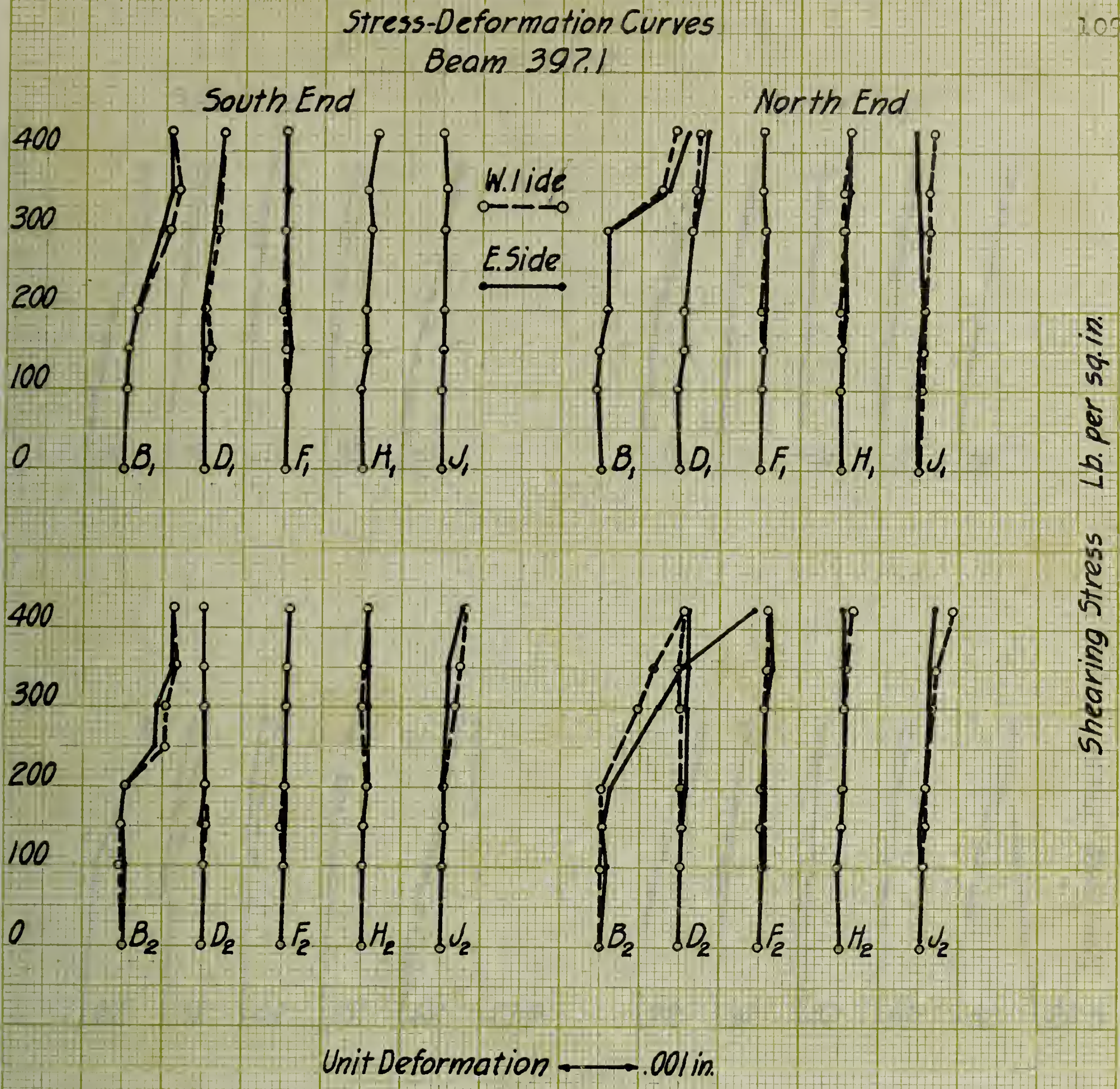
Stress-Deformation Curves
Beam 396.1
South End
North End
W. Side
E. Side
400
300
200
100
0
A_1 C_1 E_1 G_1 I_1
A_2 C_2 E_2 G_2 I_2
Shearing Stress Lb. per sq. in.
Unit Deformation ⟶ .001 in.

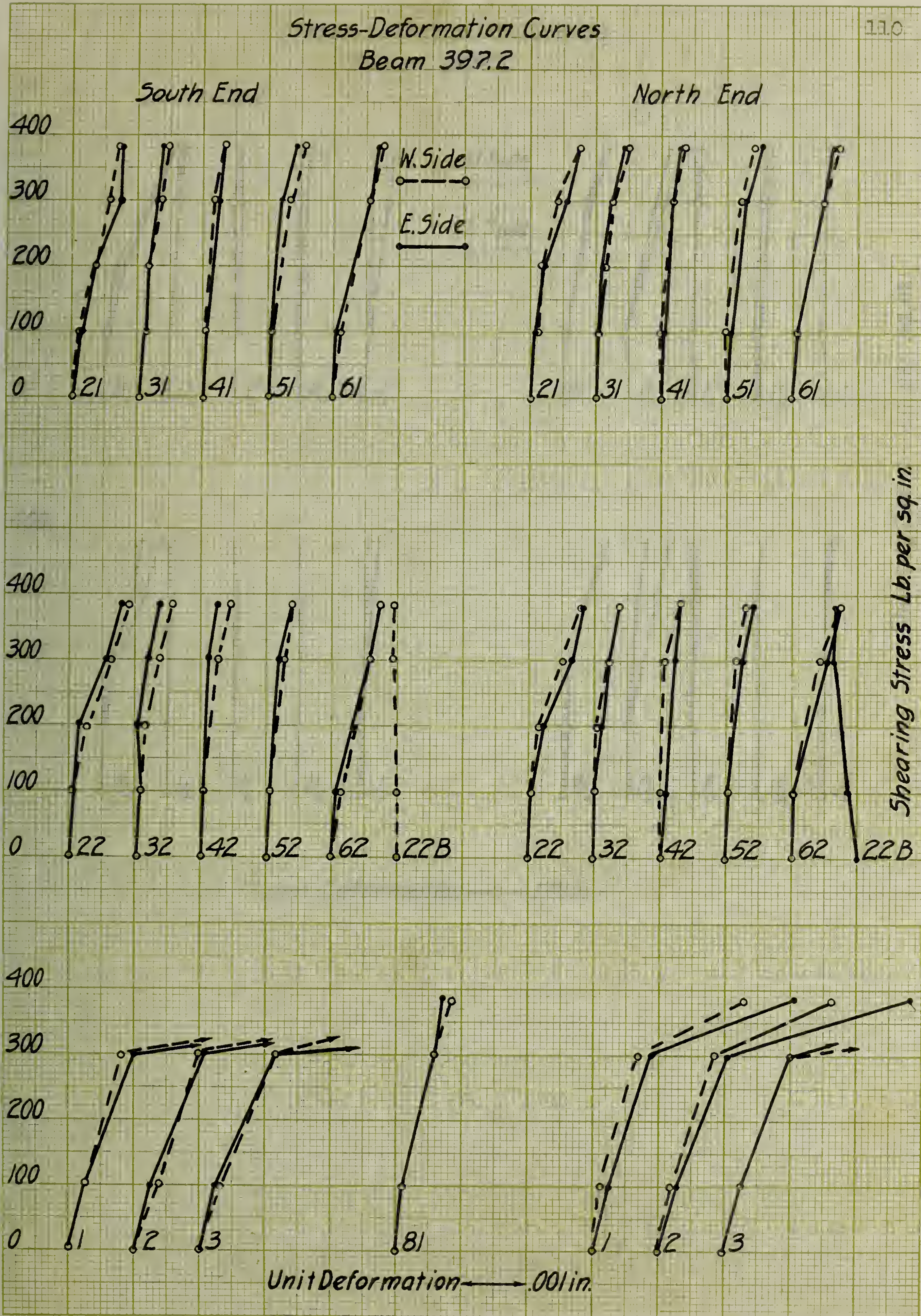

Stress-Deformation Curves
Beam 396.2
South End
North End
W. Side
E. Side
300
200
100
0
21
31
41
51
61
22
32
42
52
62
1
2
3
81
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.


Stress-Deformation Curves
Beam 396.2
South End
North End
W. Side
E. Side
300
200
100
0
A1 C1 E1 G1 I1
A2 C2 E2 G2 I2
Shearing Stress Lb. per sq. in.
Unit Deformation ——→ .001 in.

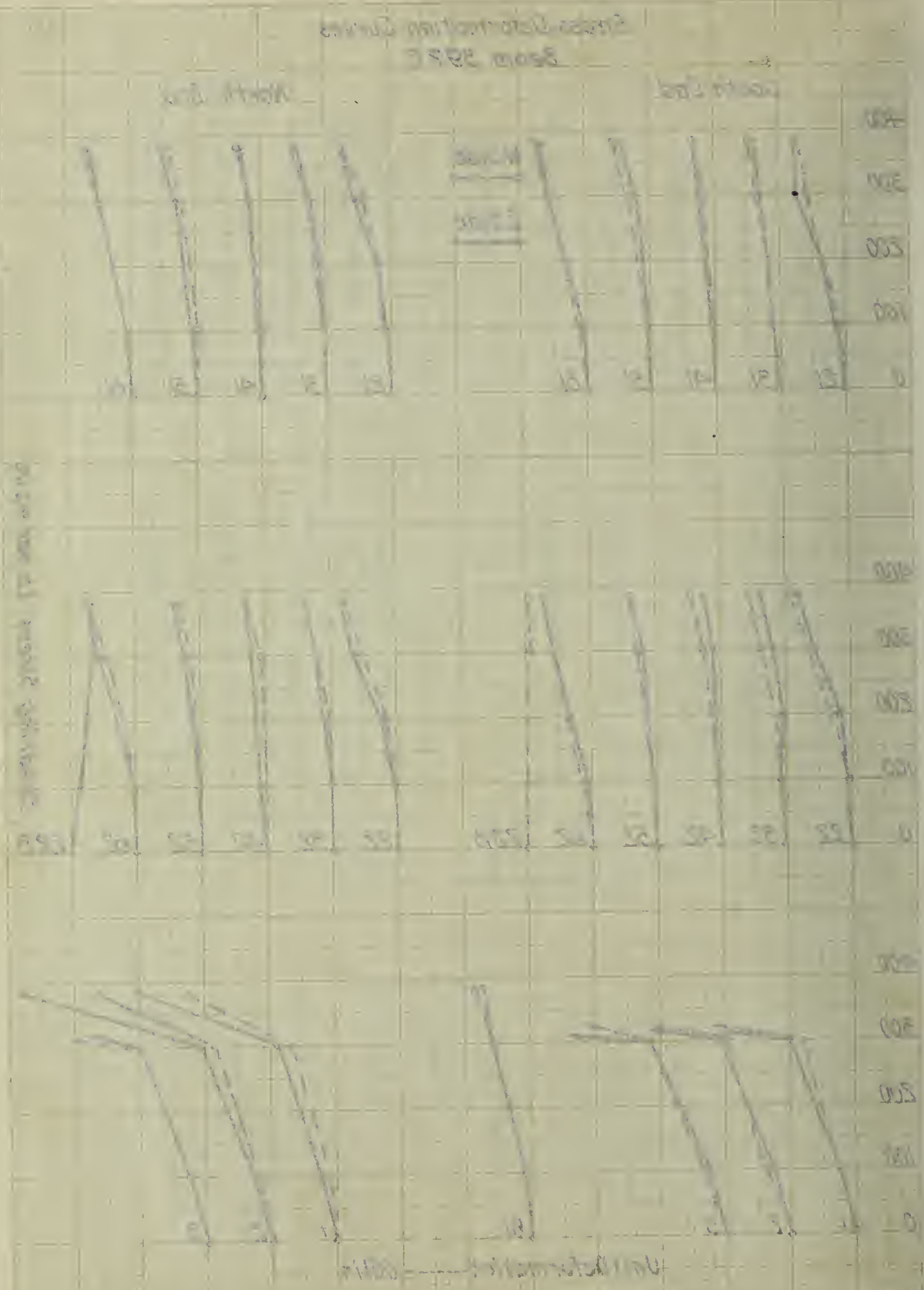


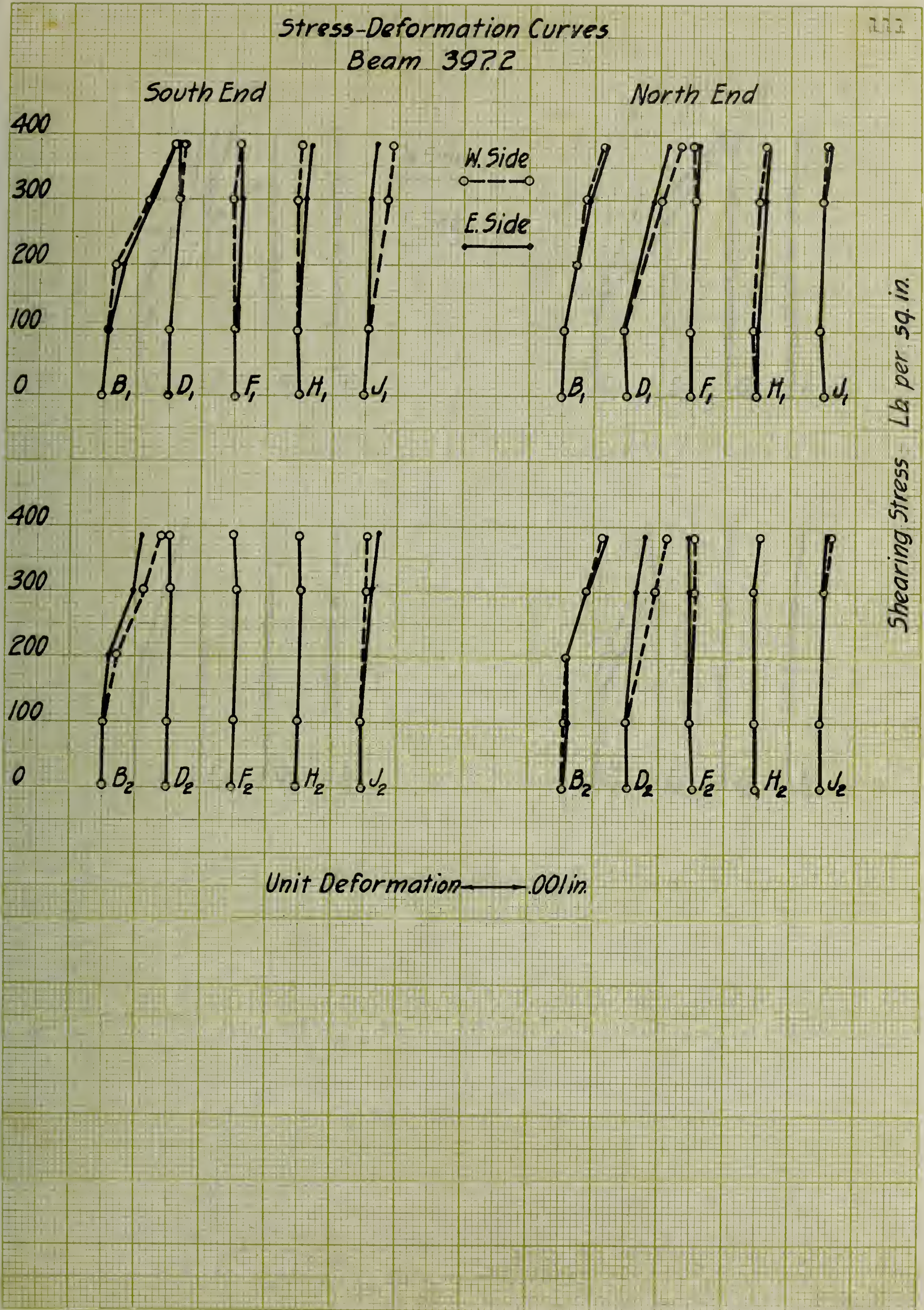
Stress-Deformation Curves
Beam 3971
South End
North End
W. Side
E. Side
400
300
200
100
0
31
51
61
31
41
51
61
22
32
42
52
22
32
52
1
2
3
81
82
1
2
3
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.

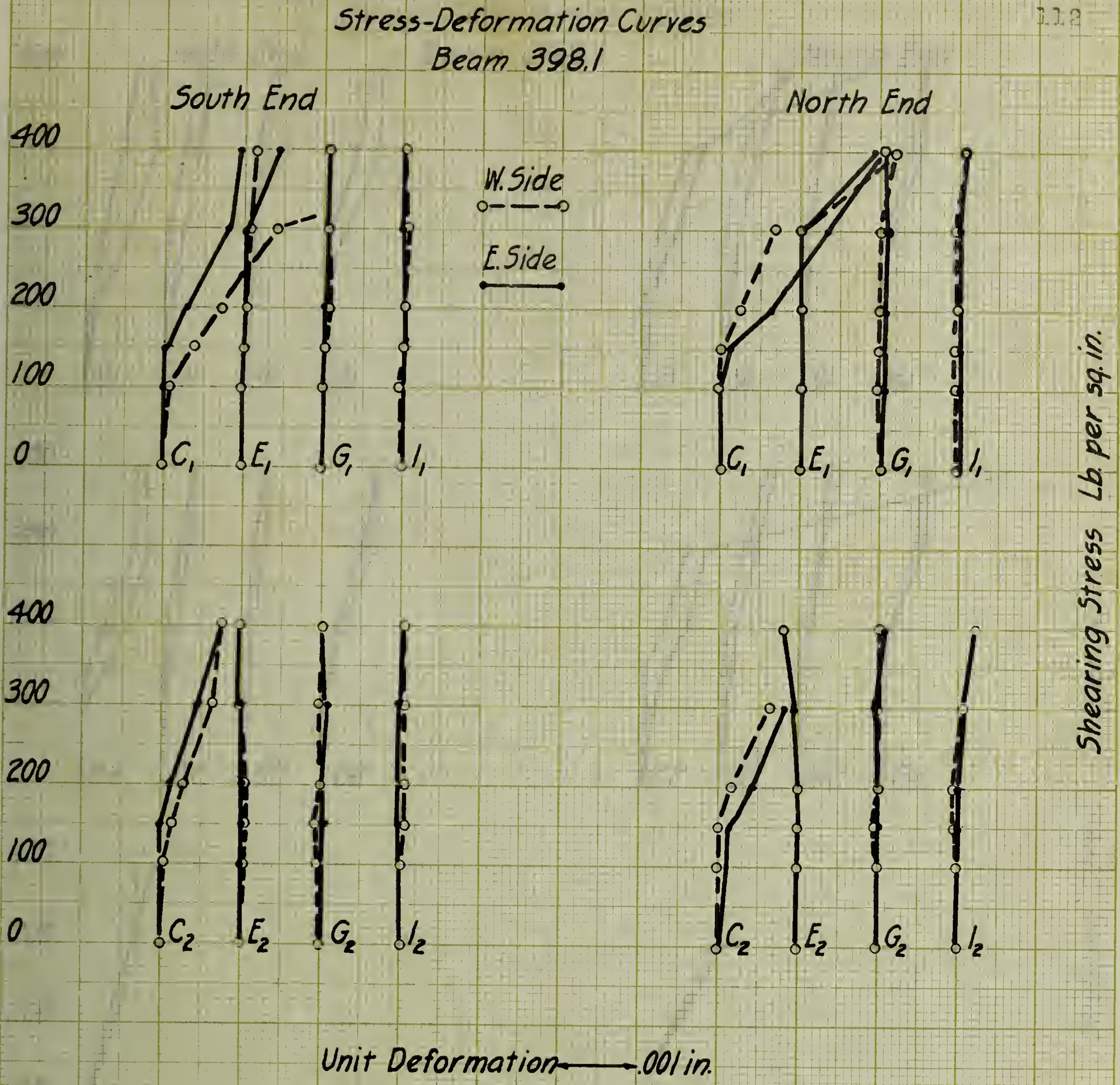

Stress-Deformation Curves
Beam 397.1
South End
North End
W. Side
E. Side
400
300
200
100
0
B1
D1
F1
H1
J1
B2
D2
F2
H2
J2
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

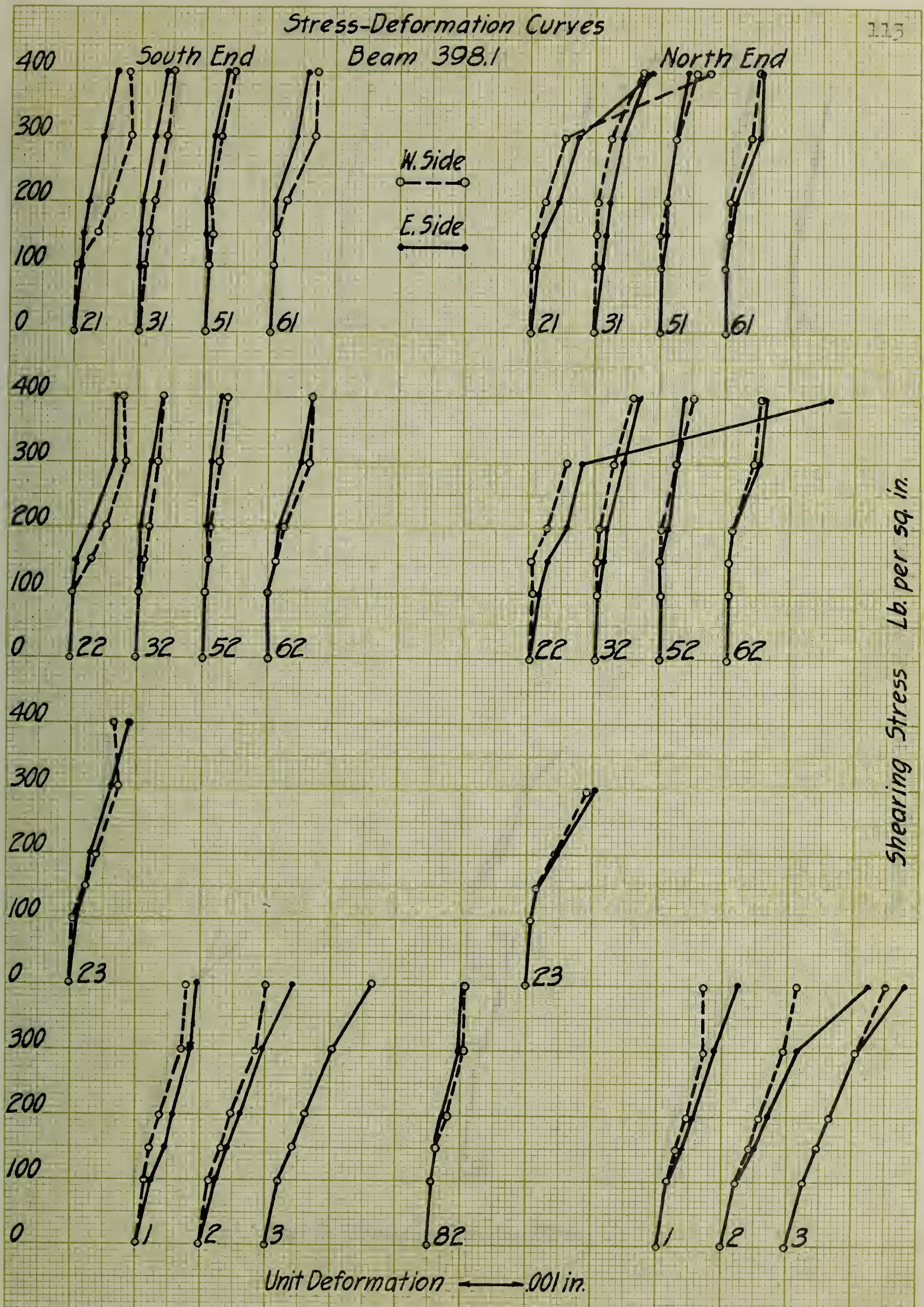


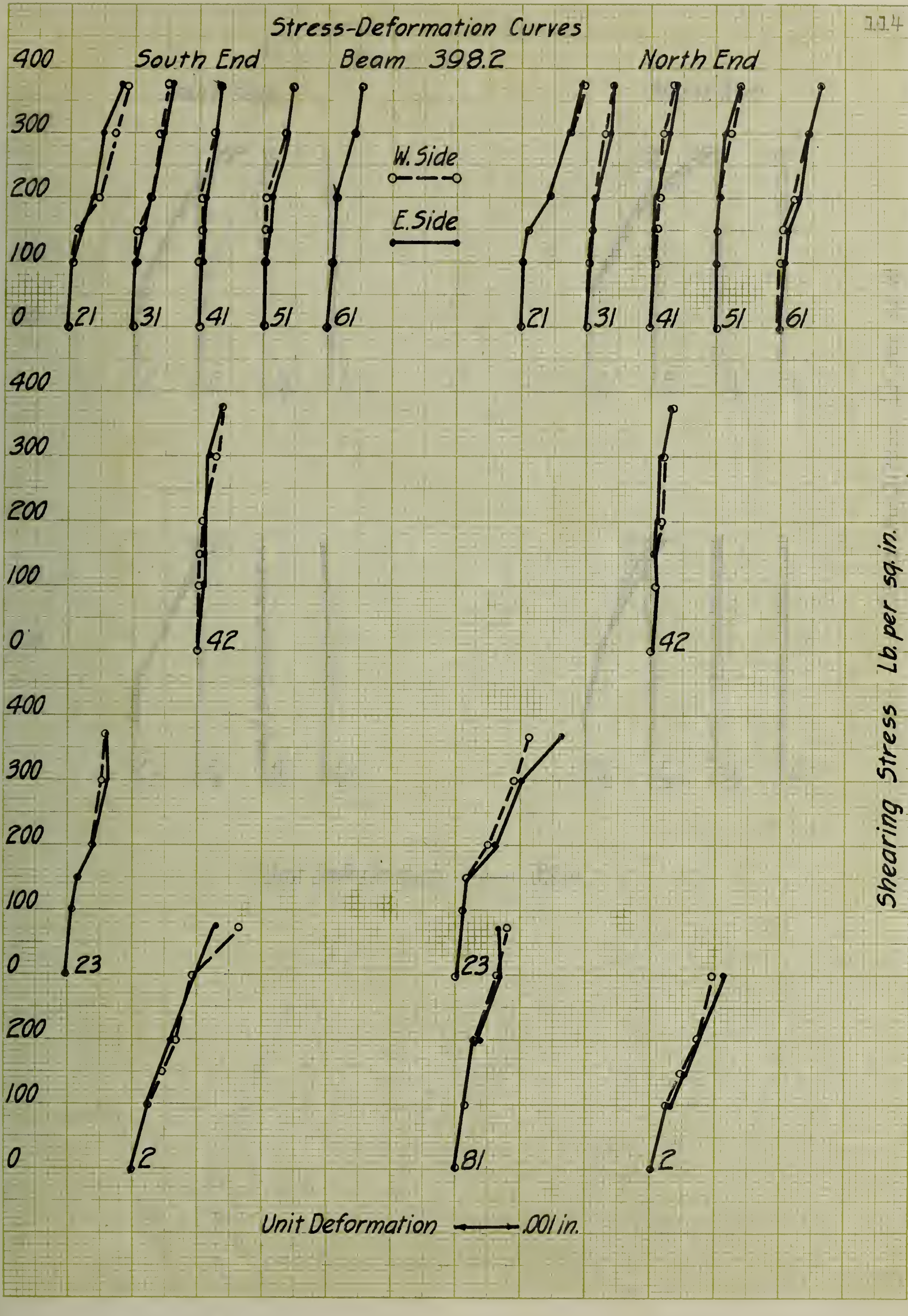
Stress-Deformation Curves
Beam 397.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
22B
1
2
3
81
Shearing Stress Lb. per sq. in.
Unit Deformation ⟵⟶ .001 in.

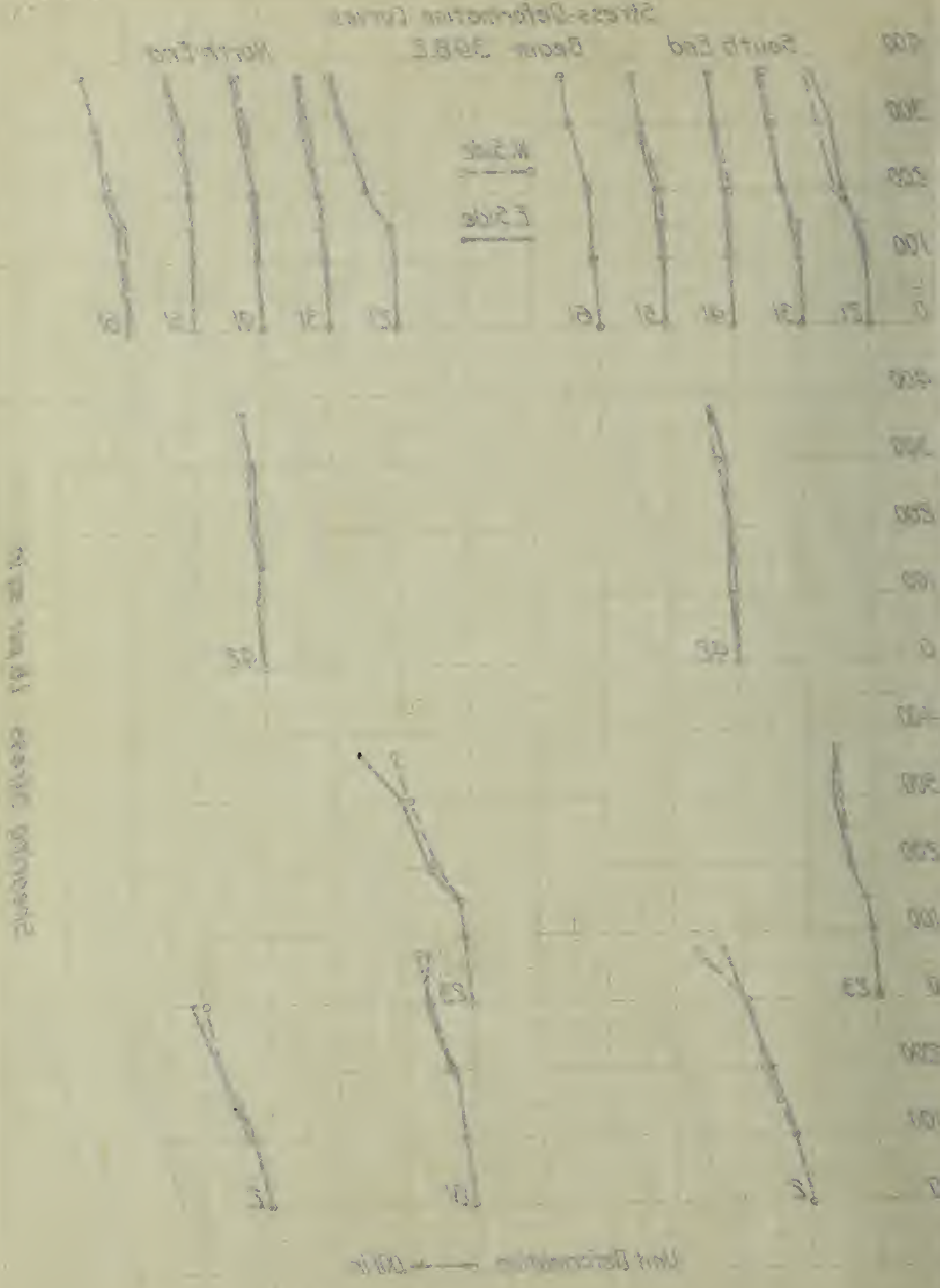


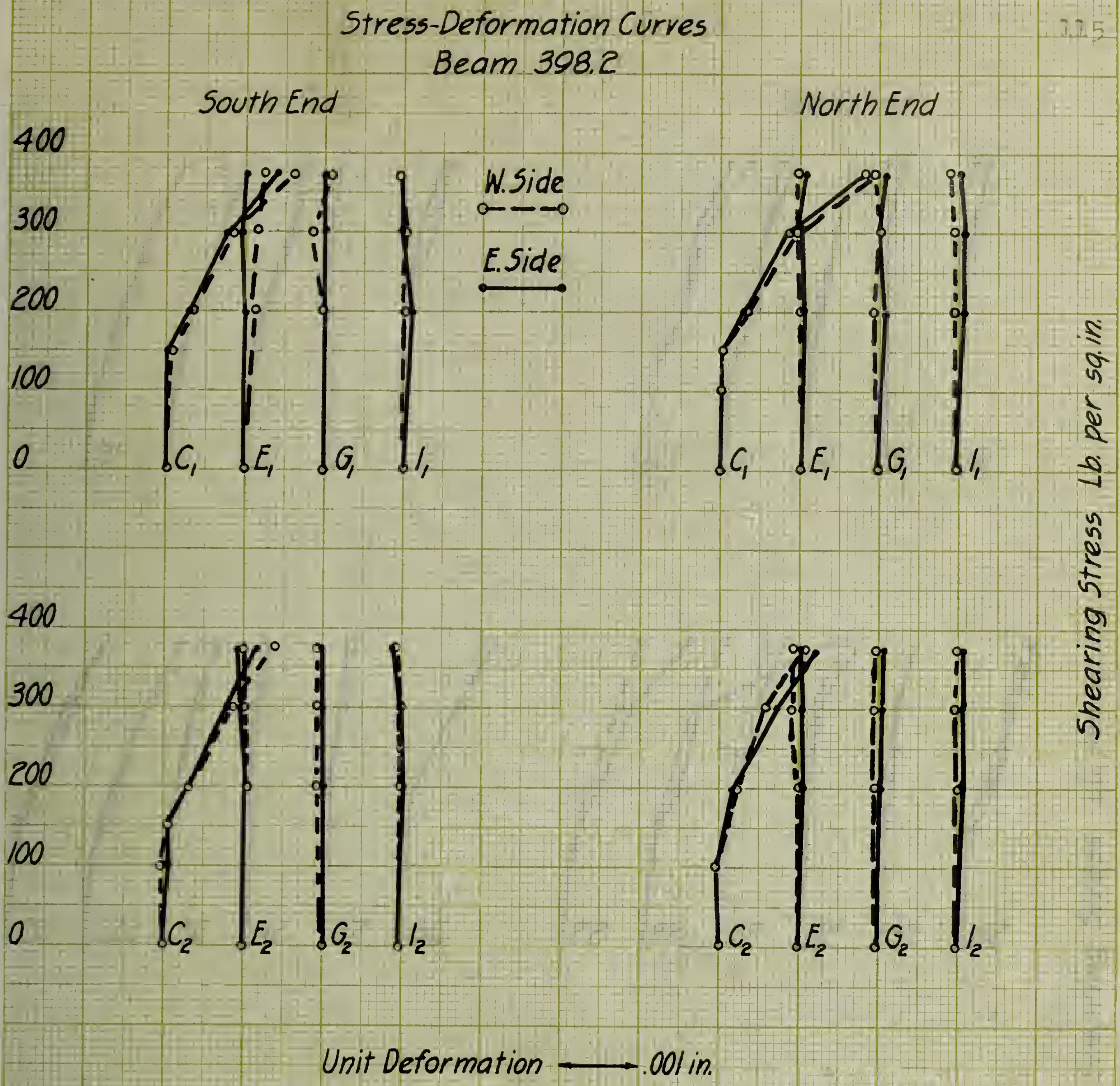

Stress-Deformation Curves
Beam 3972
South End
North End
W. Side
E. Side
400
300
200
100
0
B1
D1
F1
H1
J1
B2
D2
F2
H2
J2
Shearing Stress - Lb. per sq. in.
Unit Deformation ——— .001 in.

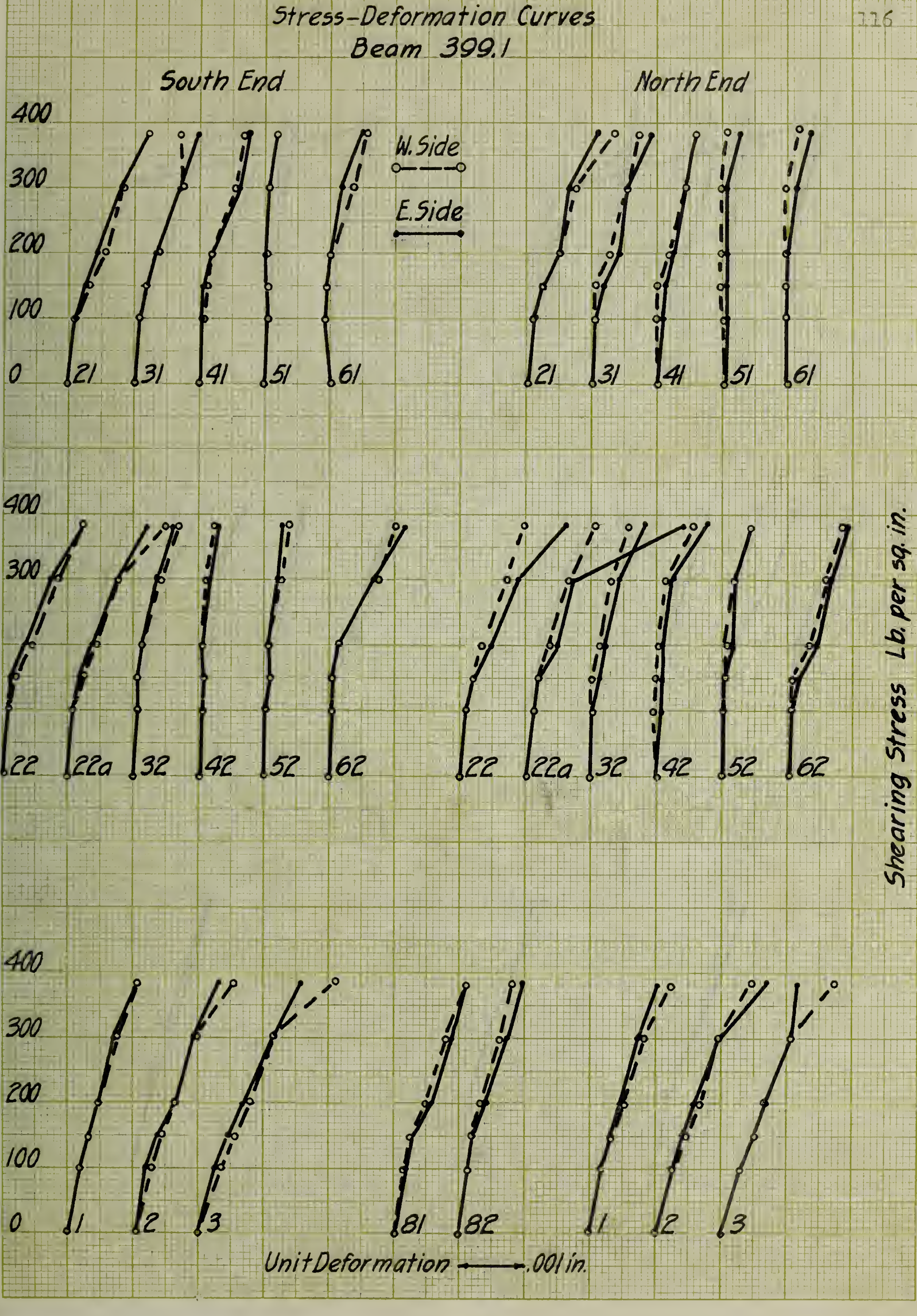

Stress-Deformation Curves
Beam 398.1
South End
North End
W. Side
E. Side
400
300
200
100
0
C1
E1
G1
I1
C2
E2
G2
I2
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.

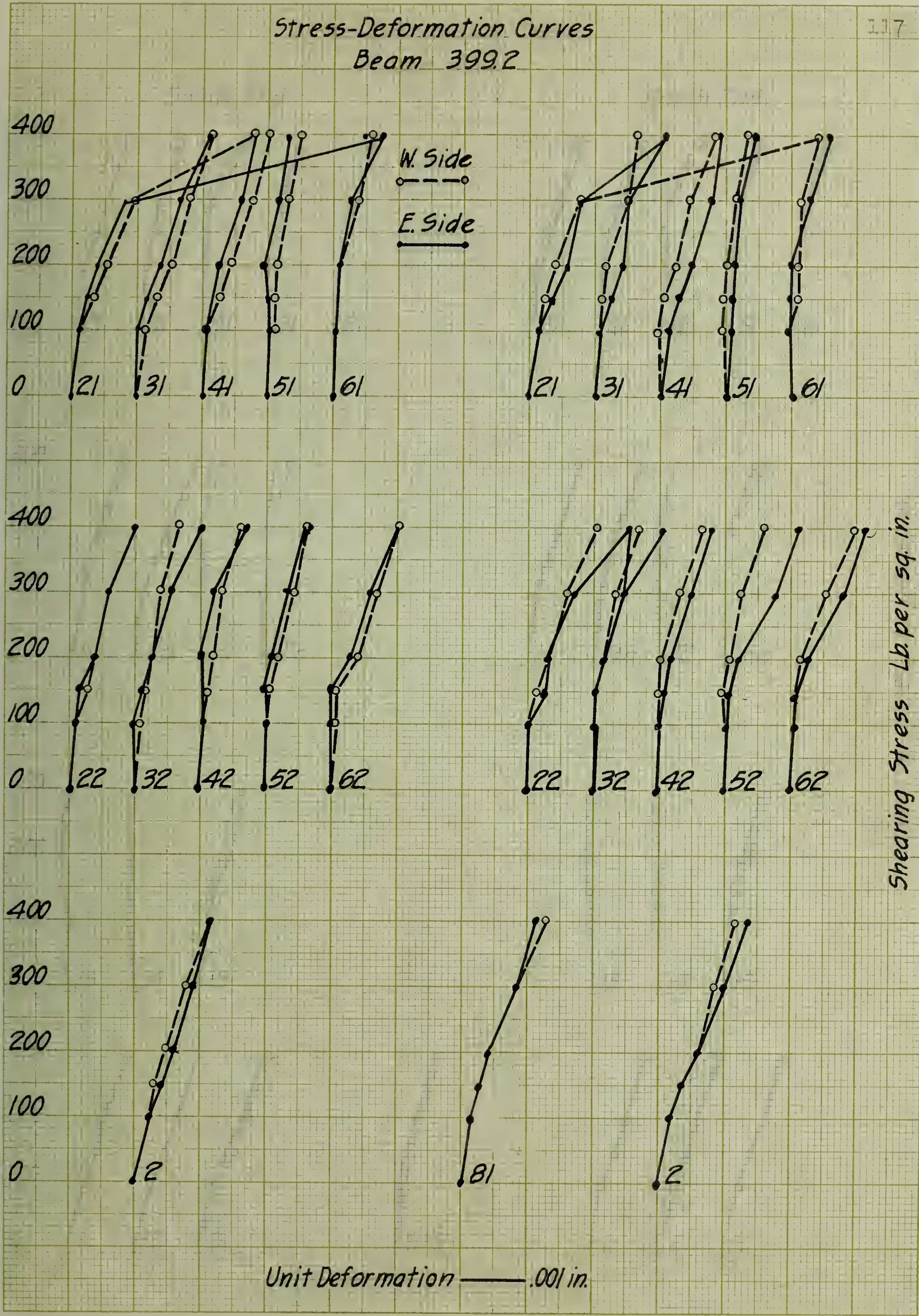

Stress-Deformation Curves
Beam 398.1
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
51
61
22
32
52
62
23
1
2
3
82
Shearing Stress Lb. per sq. in.
Unit Deformation ——— .001 in.


Stress-Deformation Curves
South End
Beam 398.2
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
42
23
2
81
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

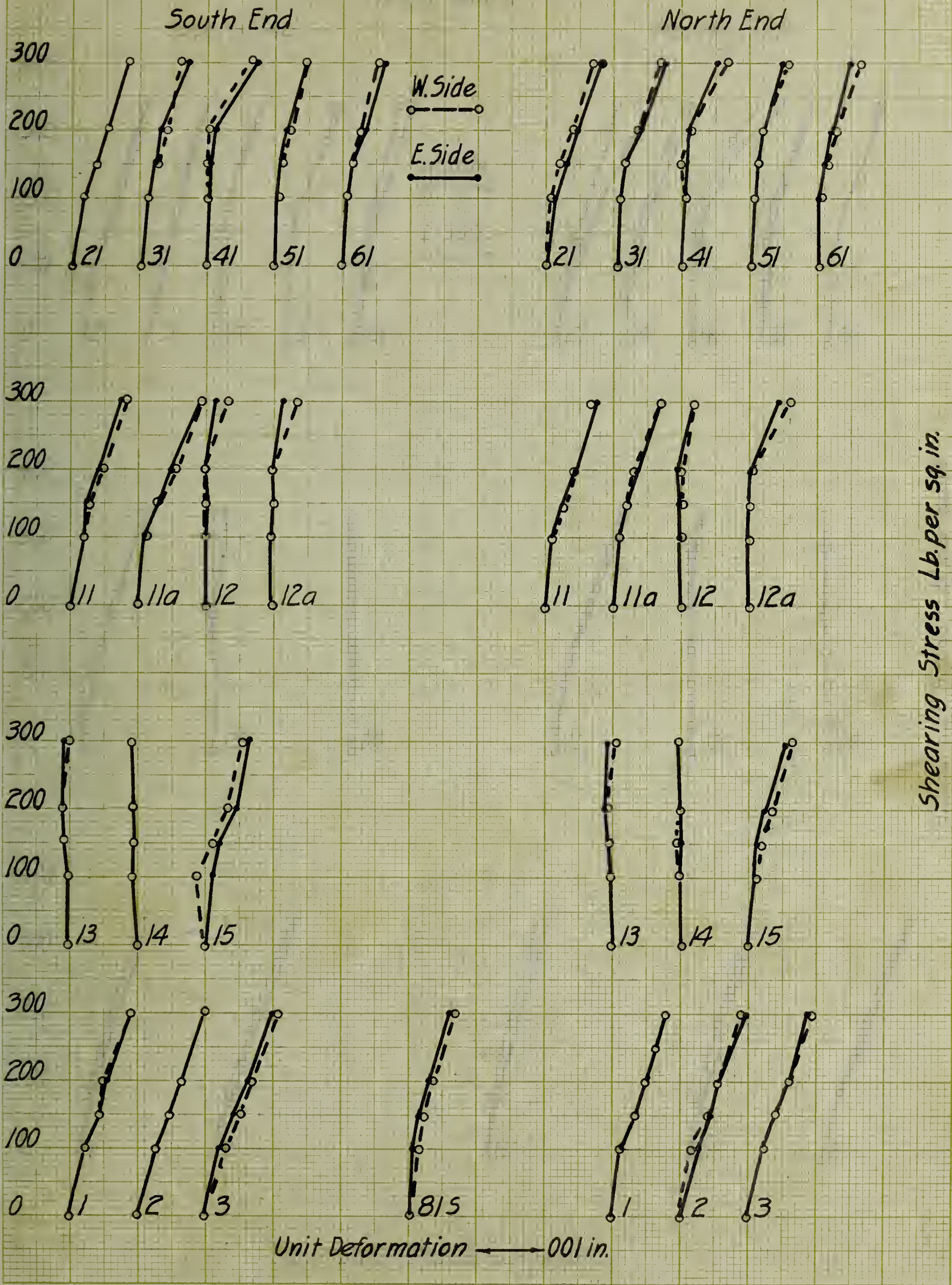

Stress-Deformation Curves
Beam 39B2
South End
North End
W. Side
E Side
Unit Deformation — .001 in
Stress lb per sq in

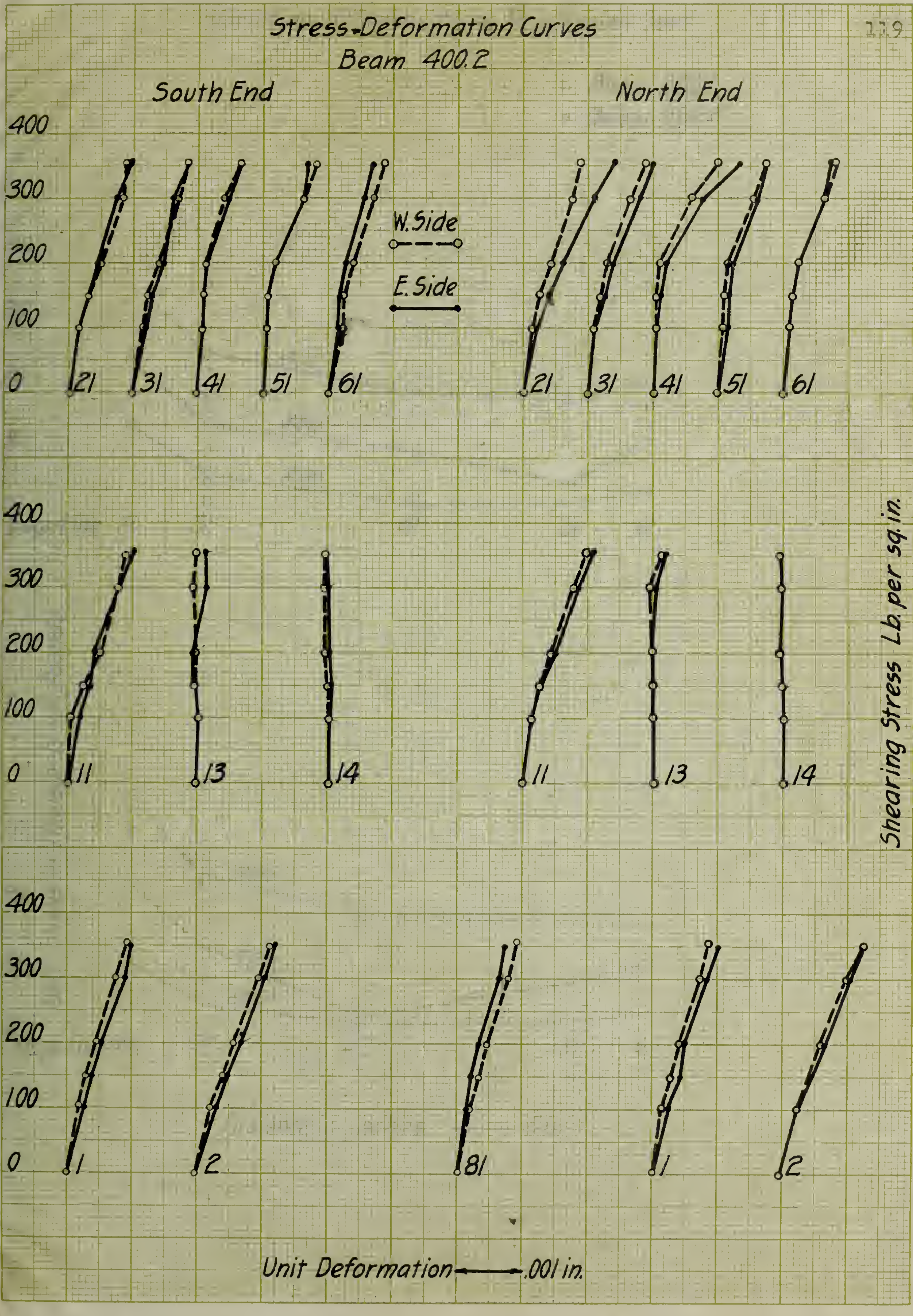

Stress-Deformation Curves
Beam 398.2
South End
North End
W. Side
E. Side
400
300
200
100
0
C1
E1
G1
I1
C2
E2
G2
I2
Shearing Stress Lb. per sq. in.
Unit Deformation ⟶ .001 in.

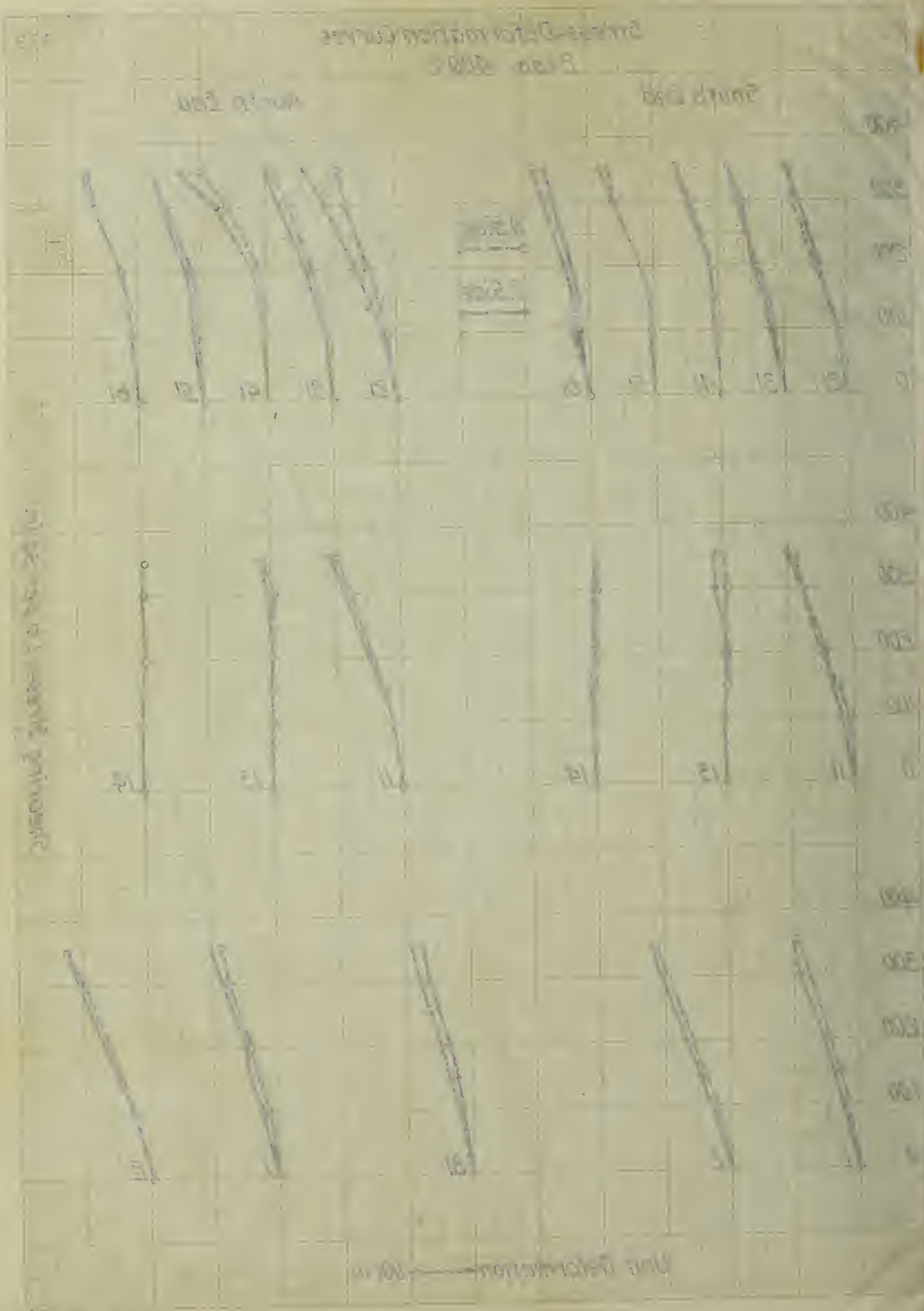

Stress-Deformation Curves
Beam 399.1
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
22a
32
42
52
62
1
2
3
81
82
Shearing Stress Lb. per sq. in.
Unit Deformation .001 in.

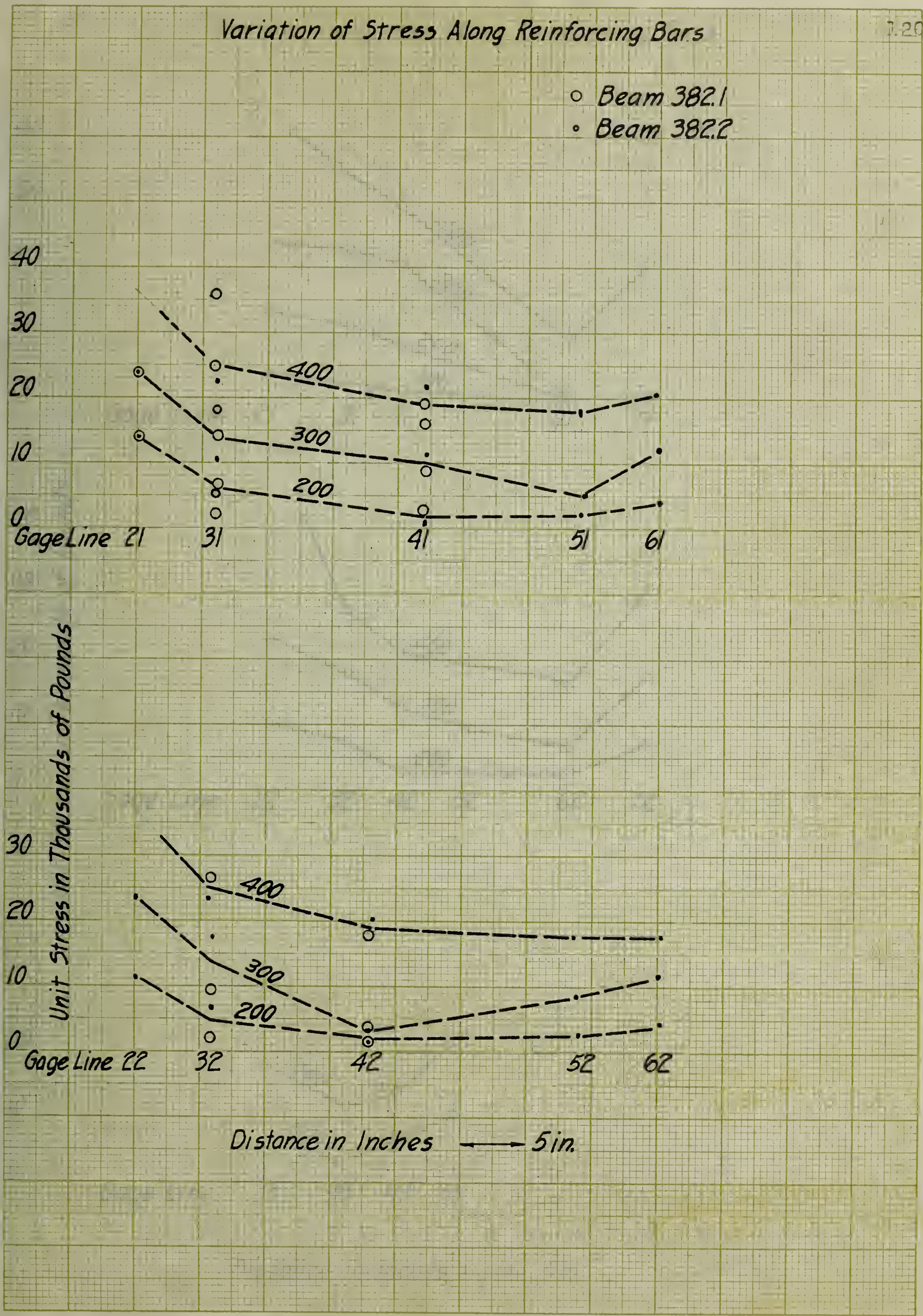

Stress-Deformation Curves
Beam 399.2
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
22
32
42
52
62
2
81
Shearing Stress Lb. per sq. in.
Unit Deformation —— .001 in.

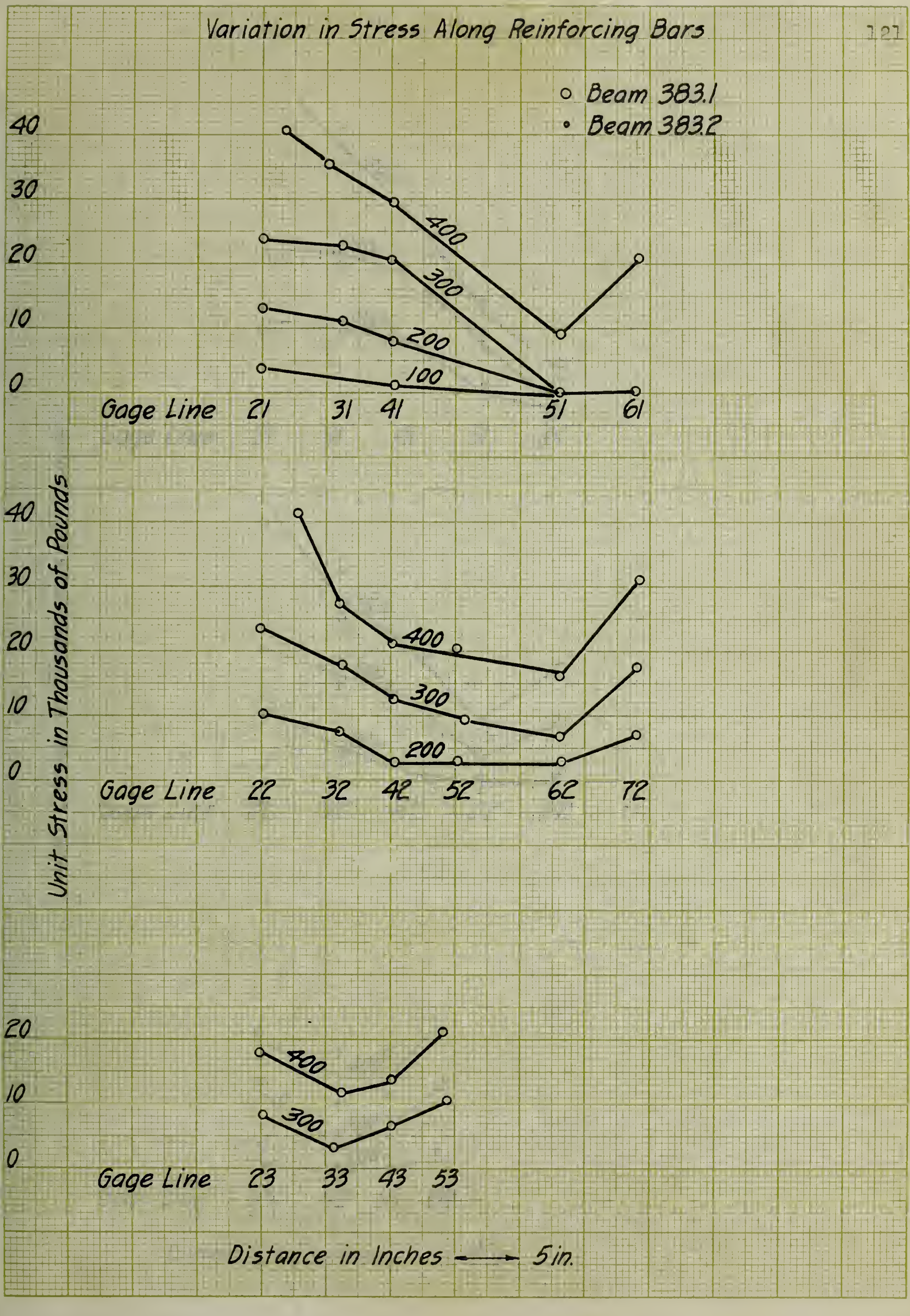
Stress-Deformation Curves
Beam 400.1



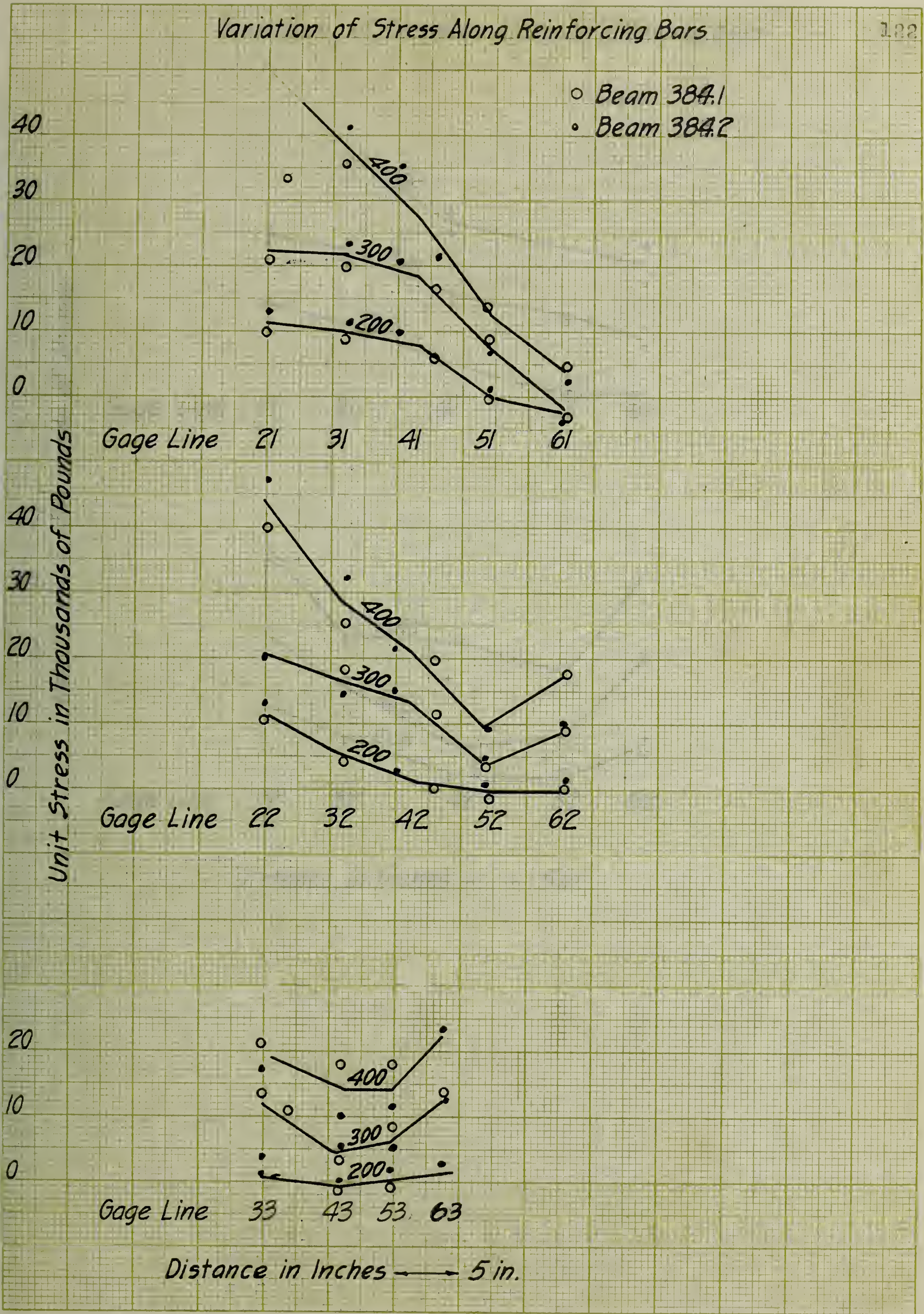

Stress-Deformation Curves
Beam 400.2
South End
North End
W. Side
E. Side
400
300
200
100
0
21
31
41
51
61
11
13
14
1
2
81
Shearing Stress Lb. per sq. in.
Unit Deformation ←→ .001 in.



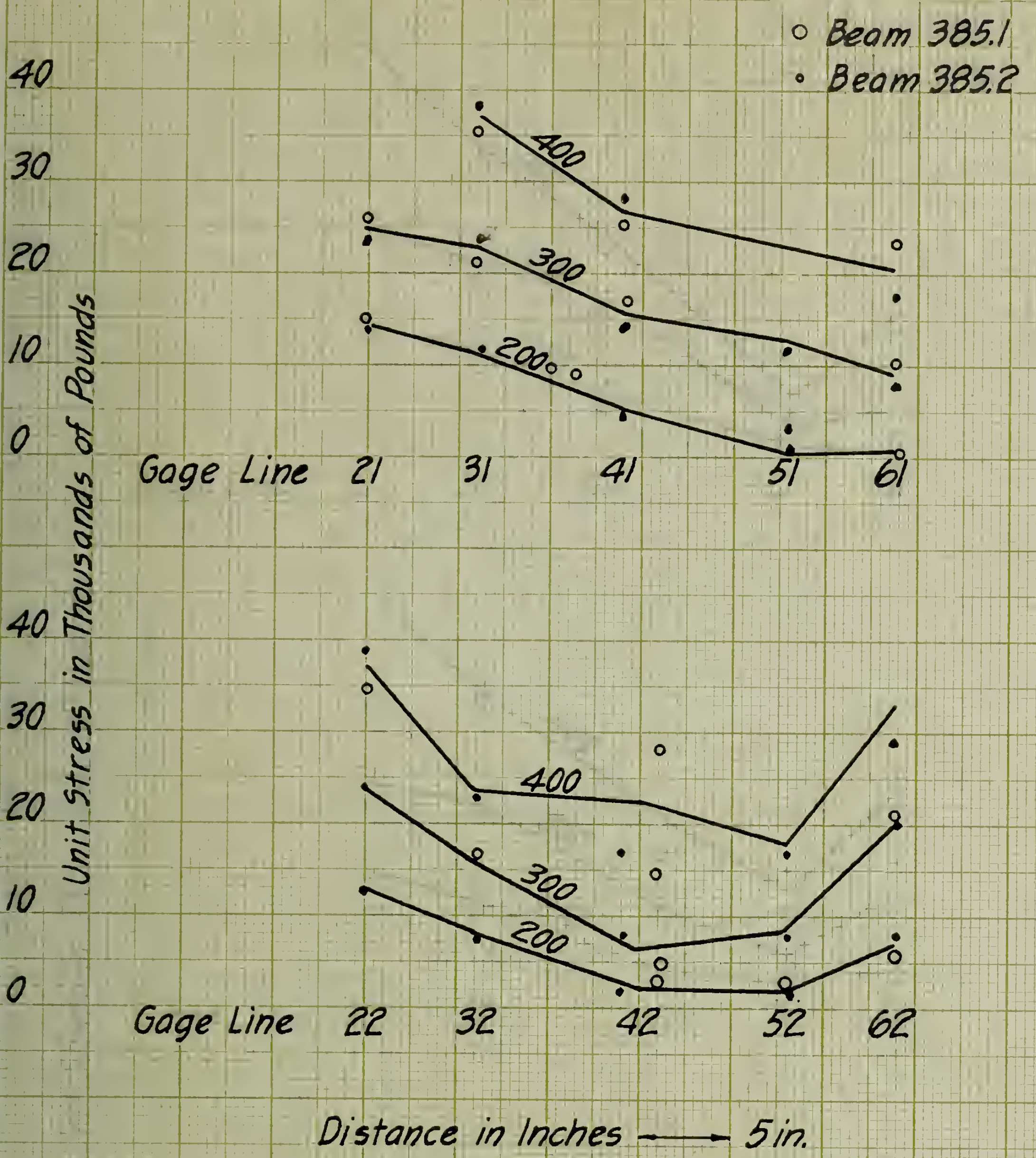

Variation of Stress Along Reinforcing Bars
Beam 382.1
Beam 382.2
40
30
20
10
0
400
300
200
Gage Line 21
31
41
51
61
Unit Stress in Thousands of Pounds
30
20
10
0
400
300
200
Gage Line 22
32
42
52
62
Distance in Inches
5 in.

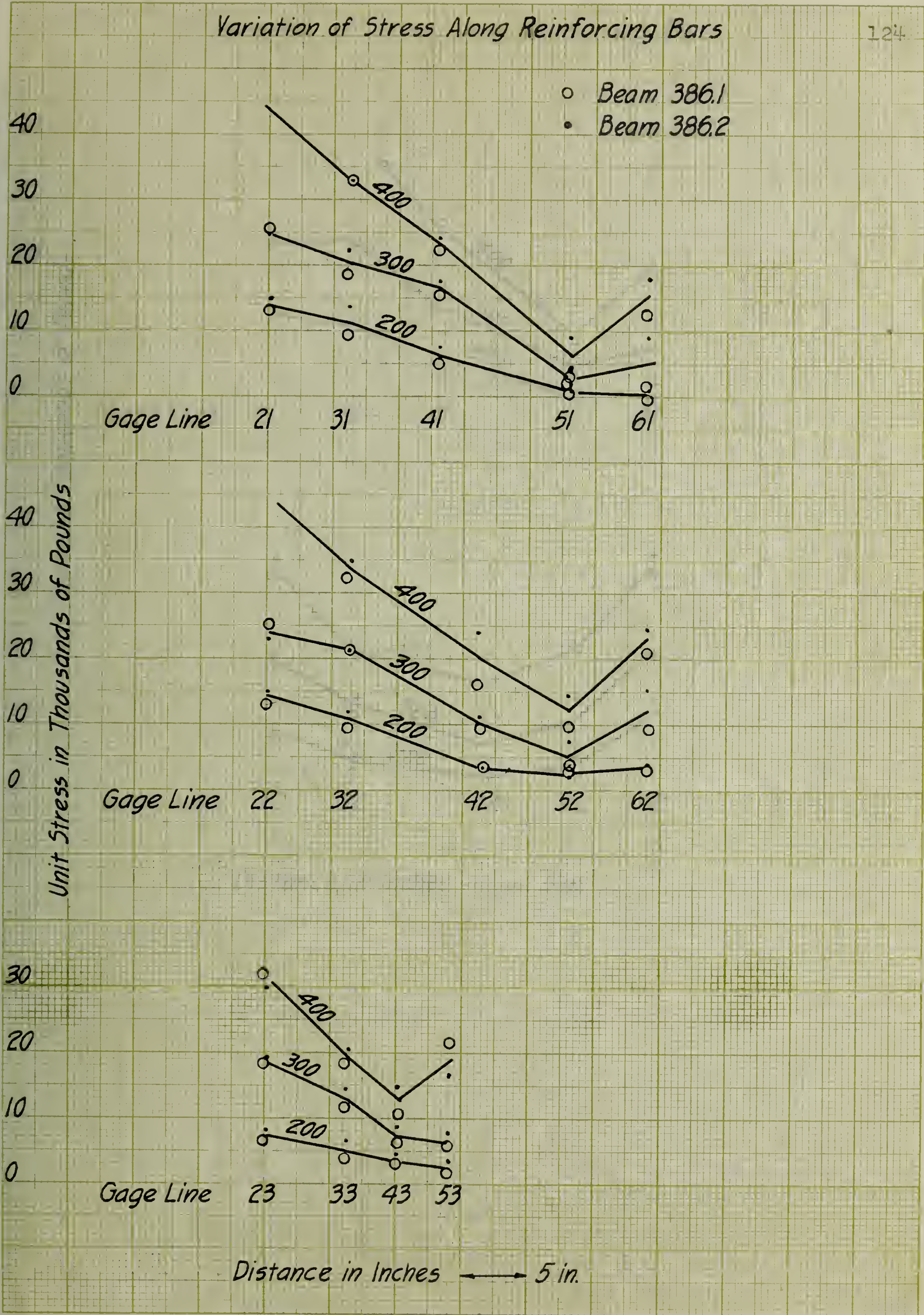


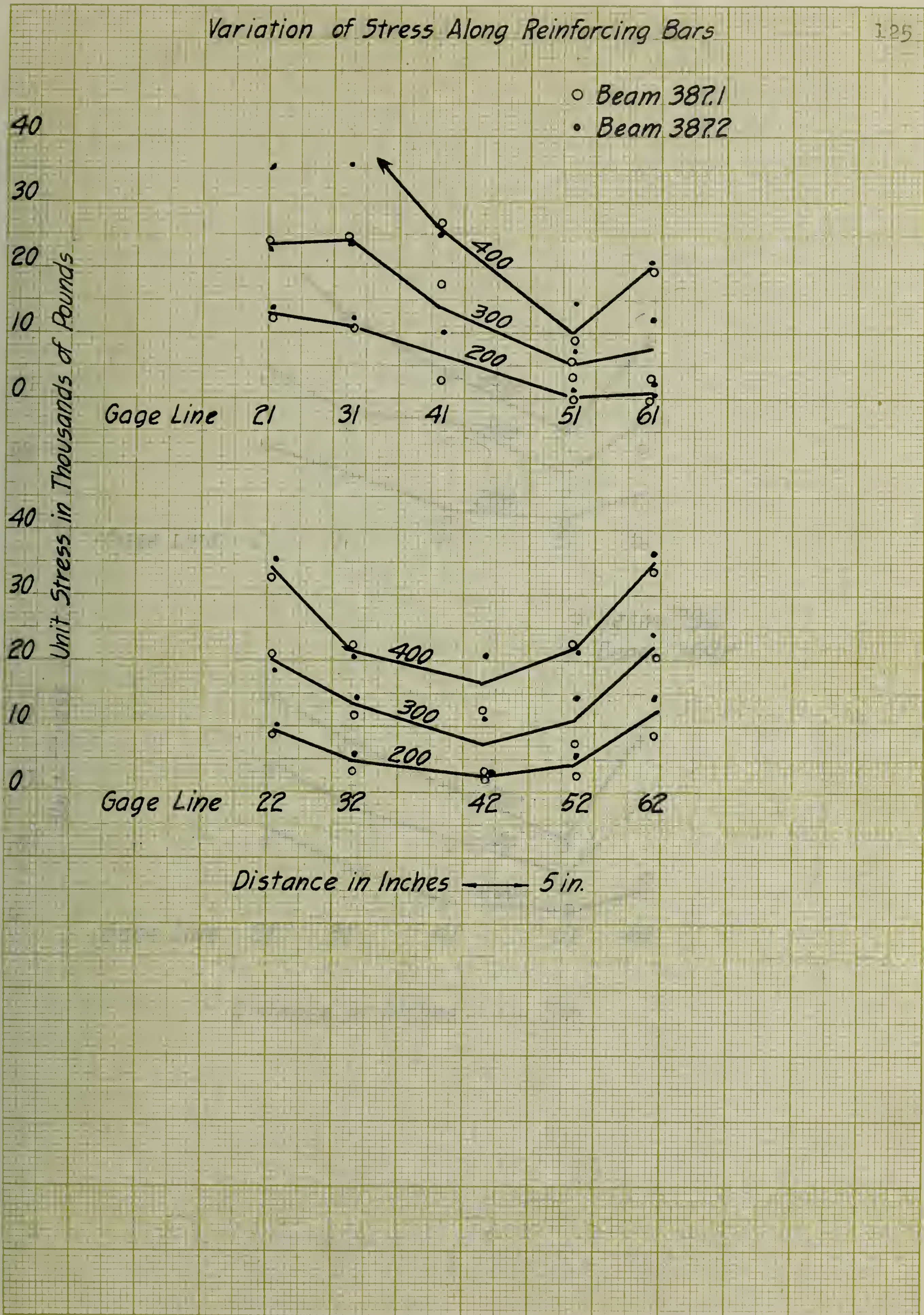
Variation in Stress Along Reinforcing Bars
121
○ Beam 383.1
• Beam 383.2
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
100
Gage Line 21 31 41 51 61
40
30
20
10
0
400
300
200
Gage Line 22 32 42 52 62 72
20
10
0
400
300
Gage Line 23 33 43 53
Distance in Inches → 5 in.


Variation of Stress Along Reinforcing Bars
○ Beam 384.1
• Beam 384.2
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
Gage Line 22 32 42 52 62
Gage Line 33 43 53 63
Distance in Inches ⟶ 5 in.

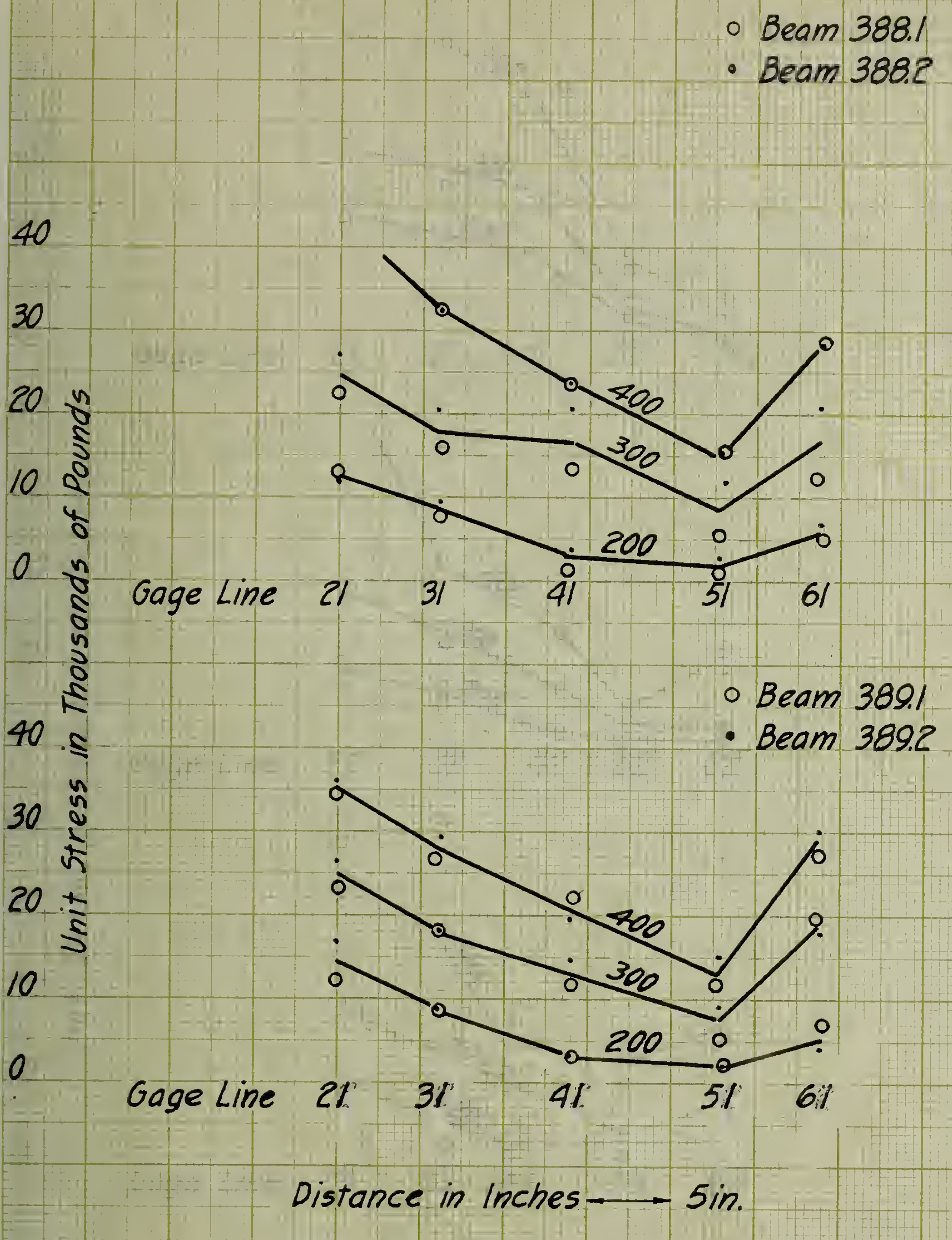
Variation of Stresses Along Reinforcing Bars

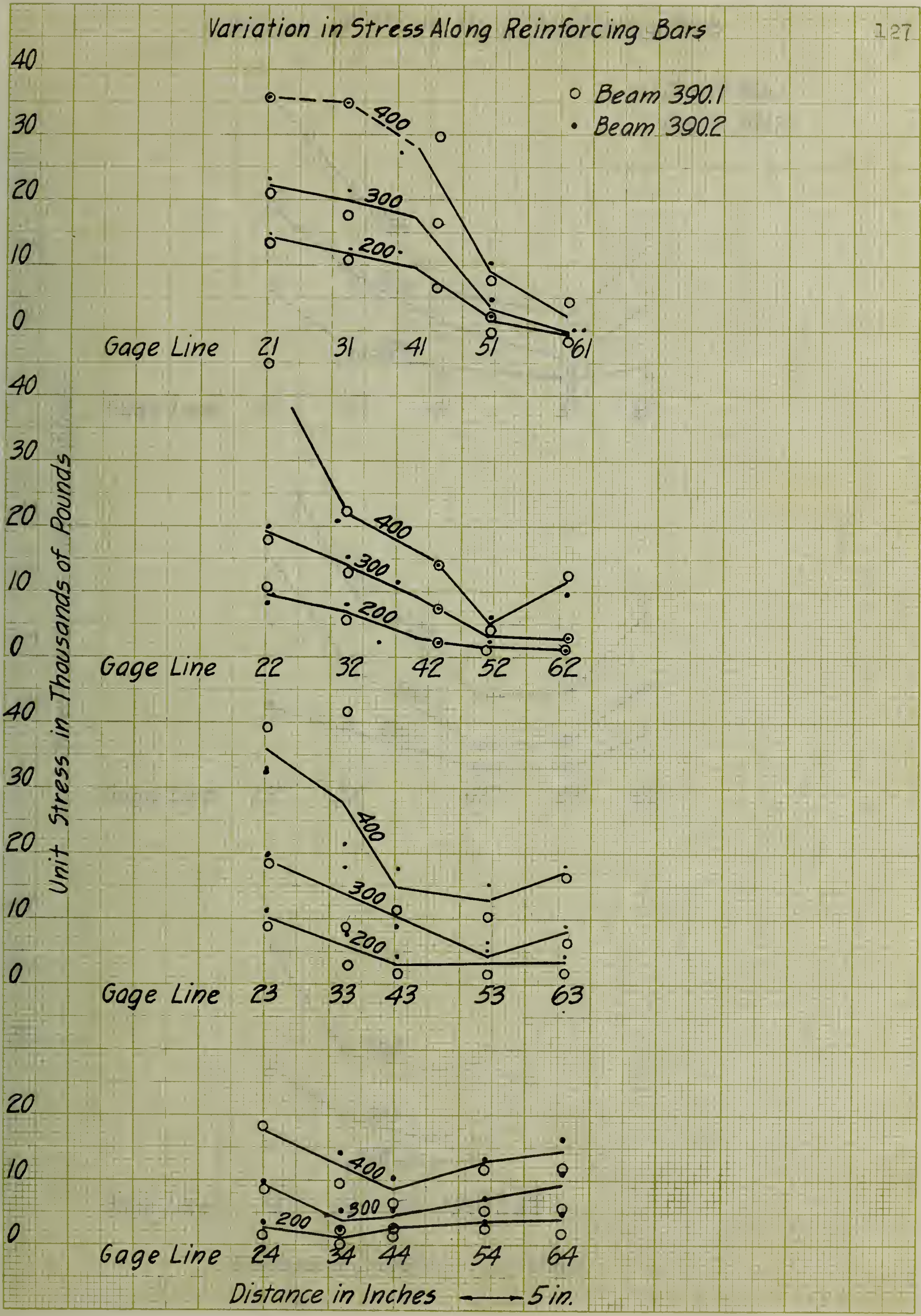


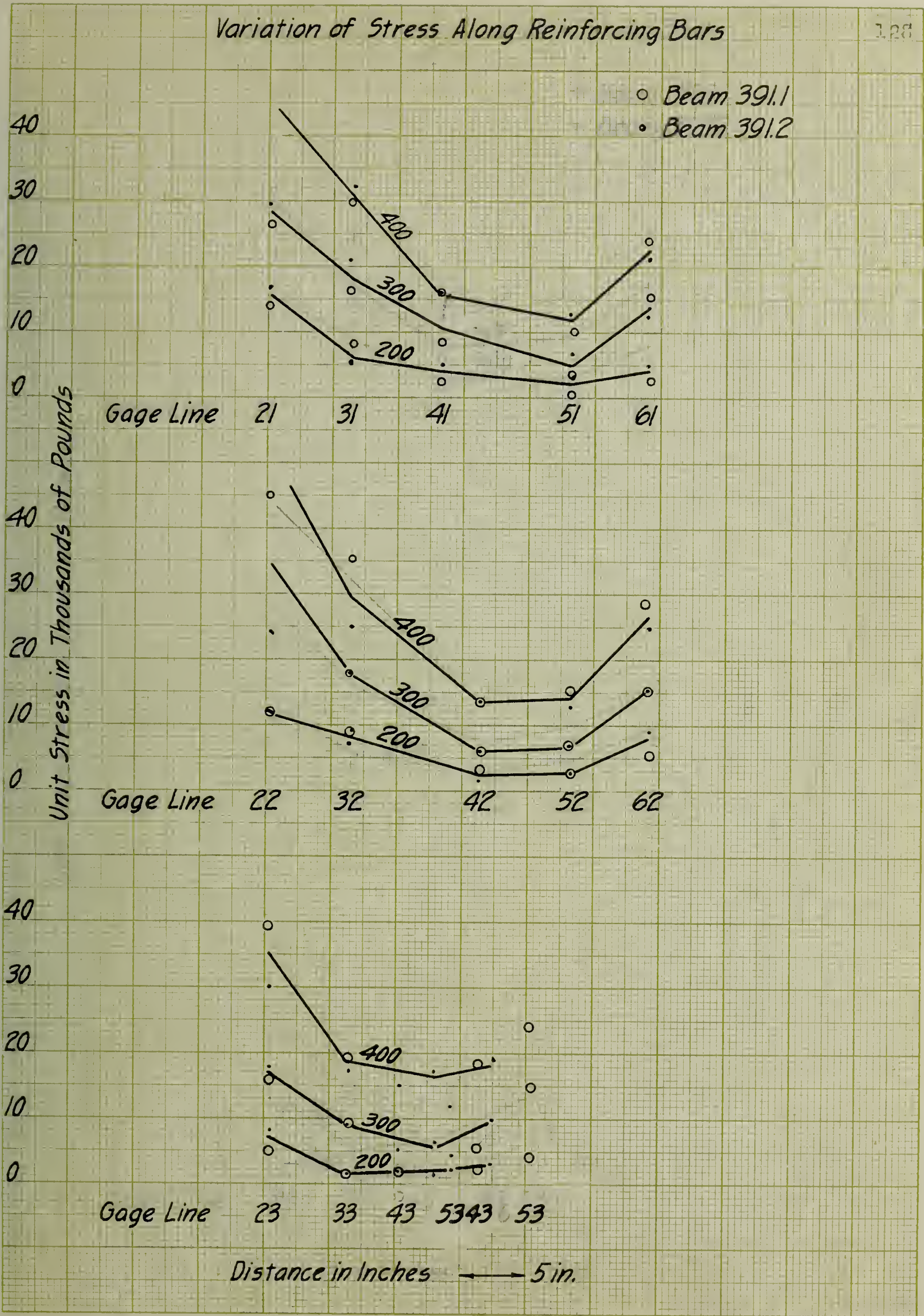

Variation of Stress Along Reinforcing Bars
Beam 386.1
Beam 386.2
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
Gage Line 22 32 42 52 62
Gage Line 23 33 43 53
Distance in Inches
5 in.


Variation of Stress Along Reinforcing Bars
○ Beam 387.1
• Beam 387.2
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
40
30
20
10
0
400
300
200
Gage Line 22 32 42 52 62
Distance in Inches ←→ 5 in.

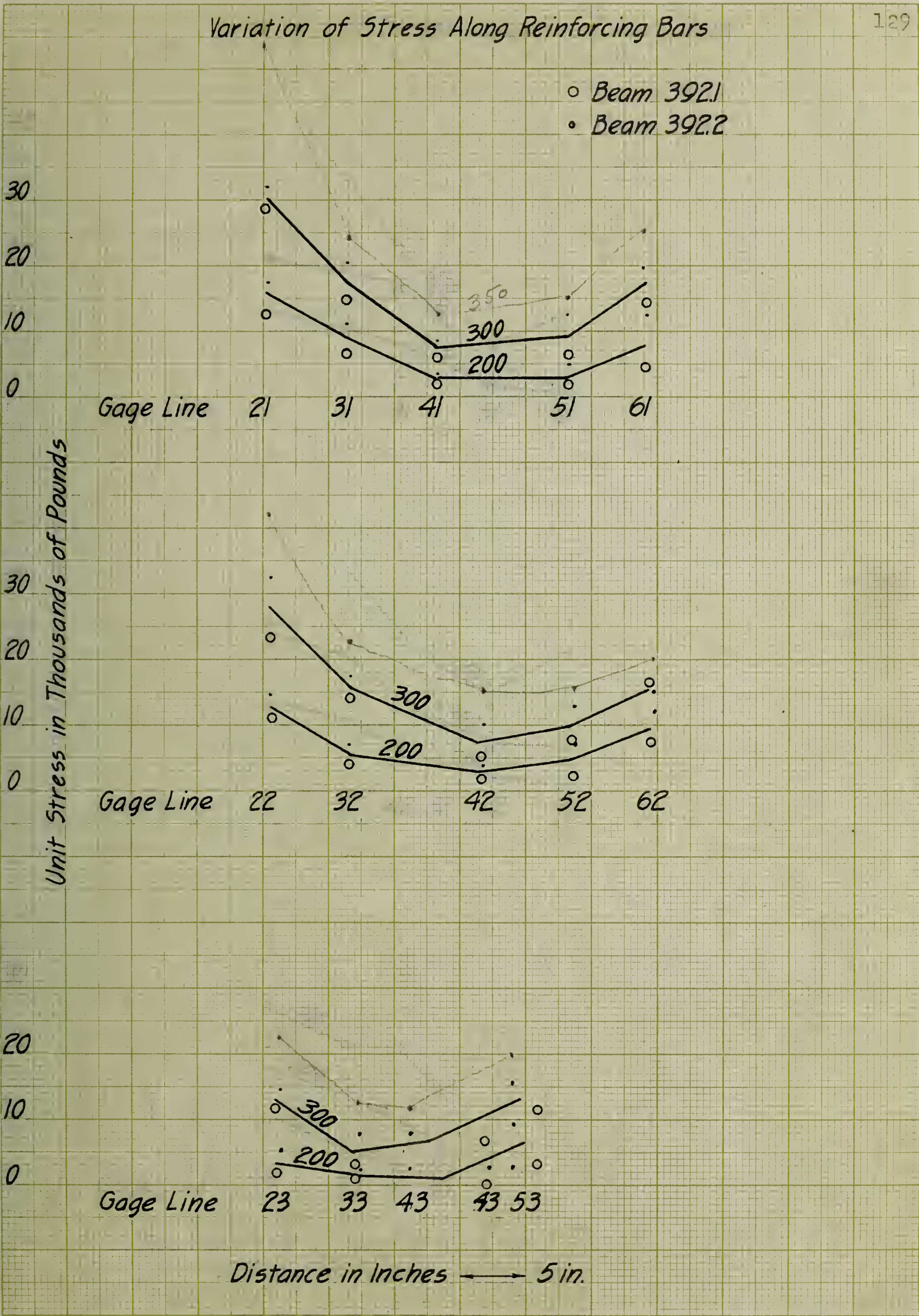
Variation of Stress Along Reinforcing Bars




Variation in Stress Along Reinforcing Bars
o Beam 390.1
• Beam 390.2
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
Gage Line 22 32 42 52 62
Gage Line 23 33 43 53 63
Gage Line 24 34 44 54 64
Distance in Inches
5 in.

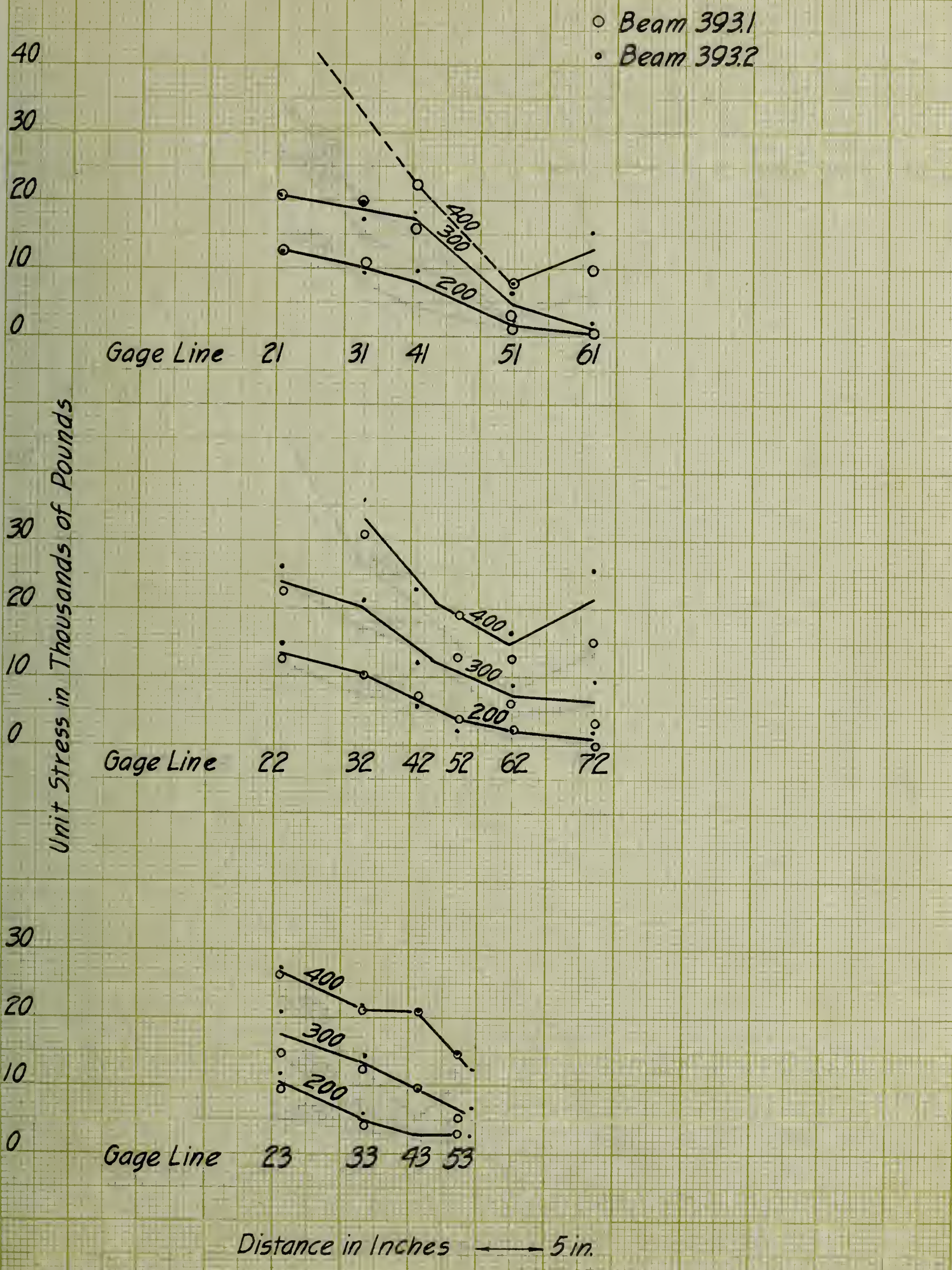


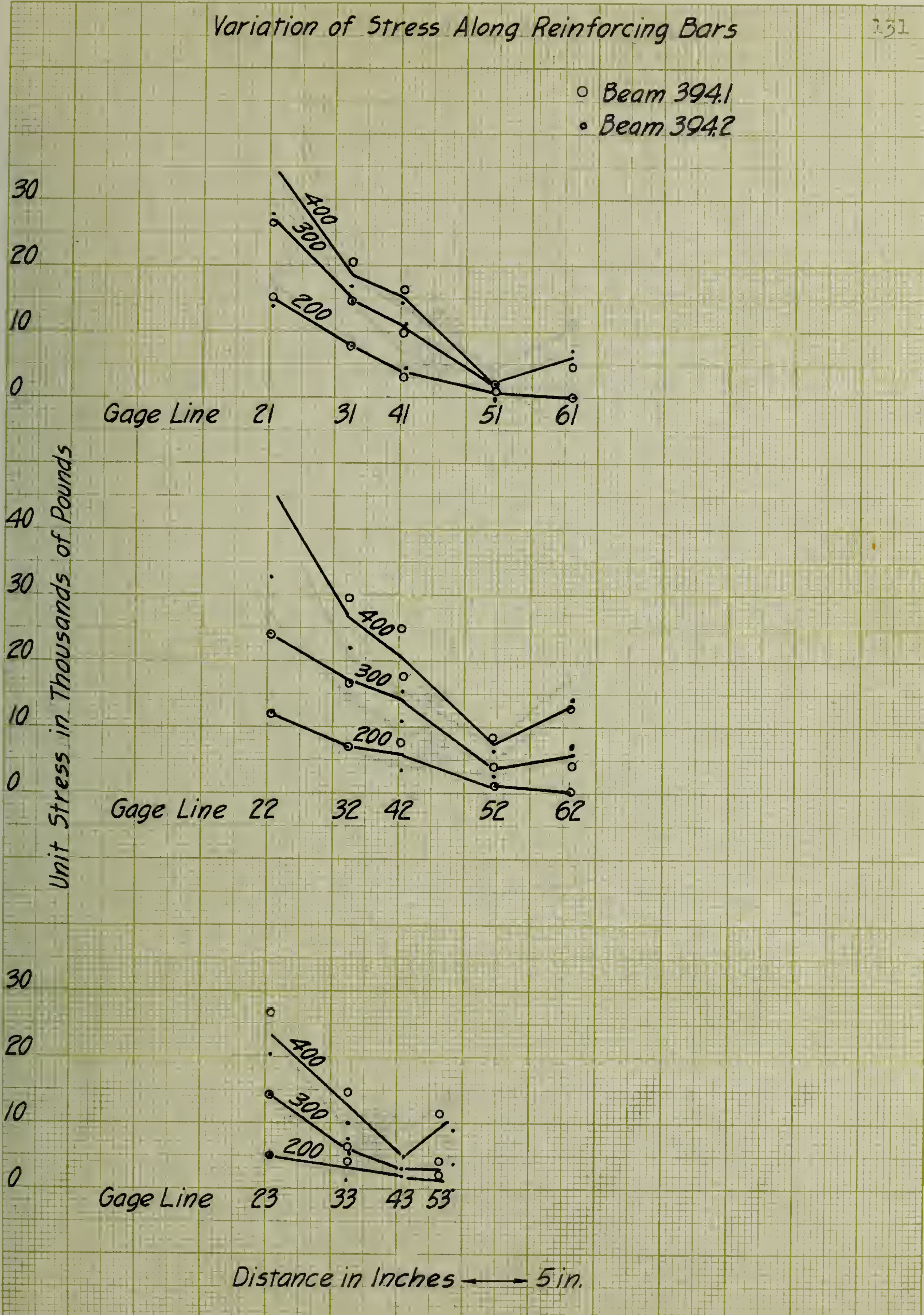
Variation of Stress Along Reinforcing Bars
128
○ Beam 391.1
• Beam 391.2
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
Gage Line 22 32 42 52 62
Gage Line 23 33 43 5343 53
Distance in Inches ← → 5 in.



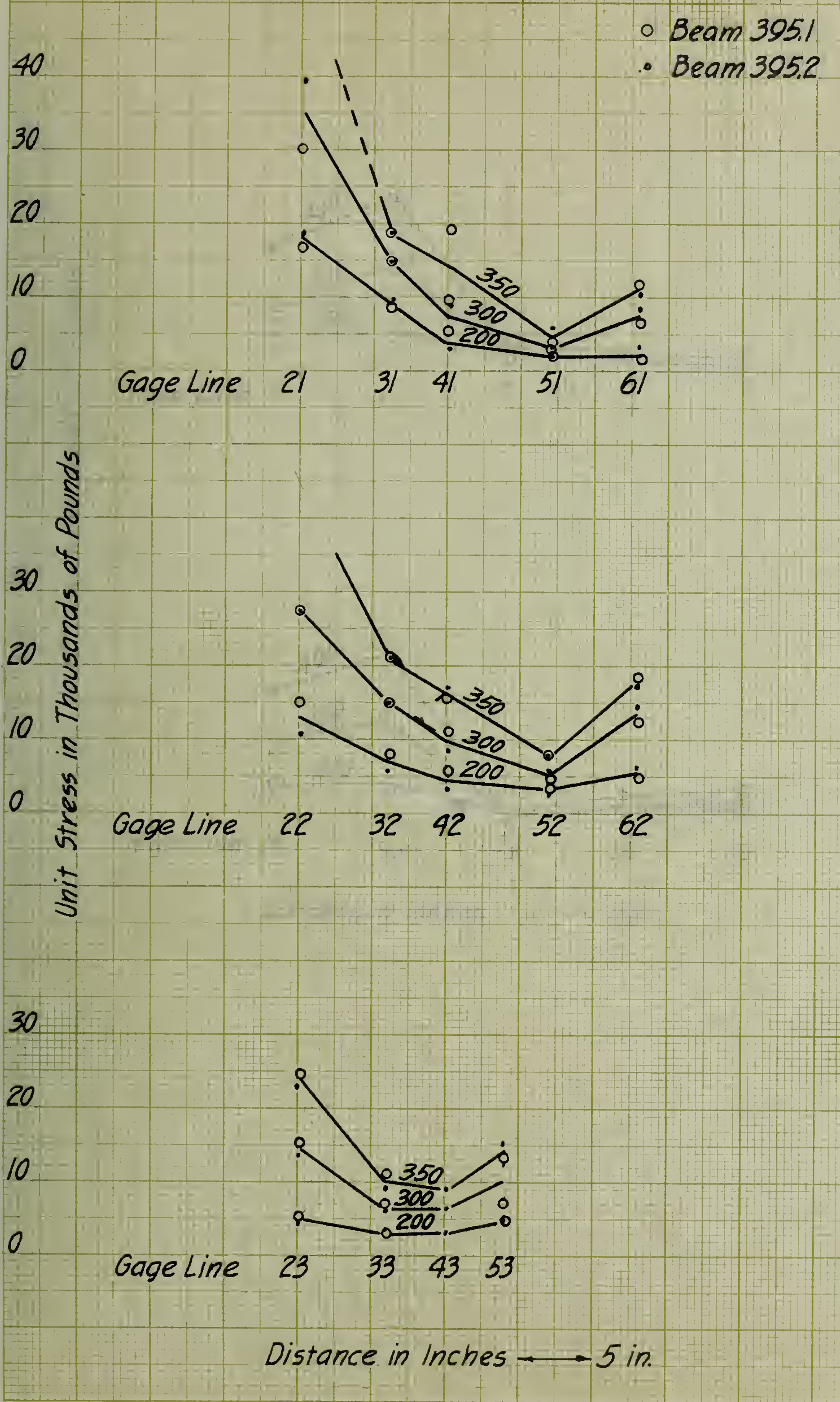
Variation of Stress Along Reinforcing Bars
o Beam 392.1
• Beam 392.2
Unit Stress in Thousands of Pounds
30
20
10
0
350
300
200
Gage Line 21 31 41 51 61
30
20
10
0
300
200
Gage Line 22 32 42 52 62
20
10
0
300
200
Gage Line 23 33 43 43 53
Distance in Inches ——— 5 in.

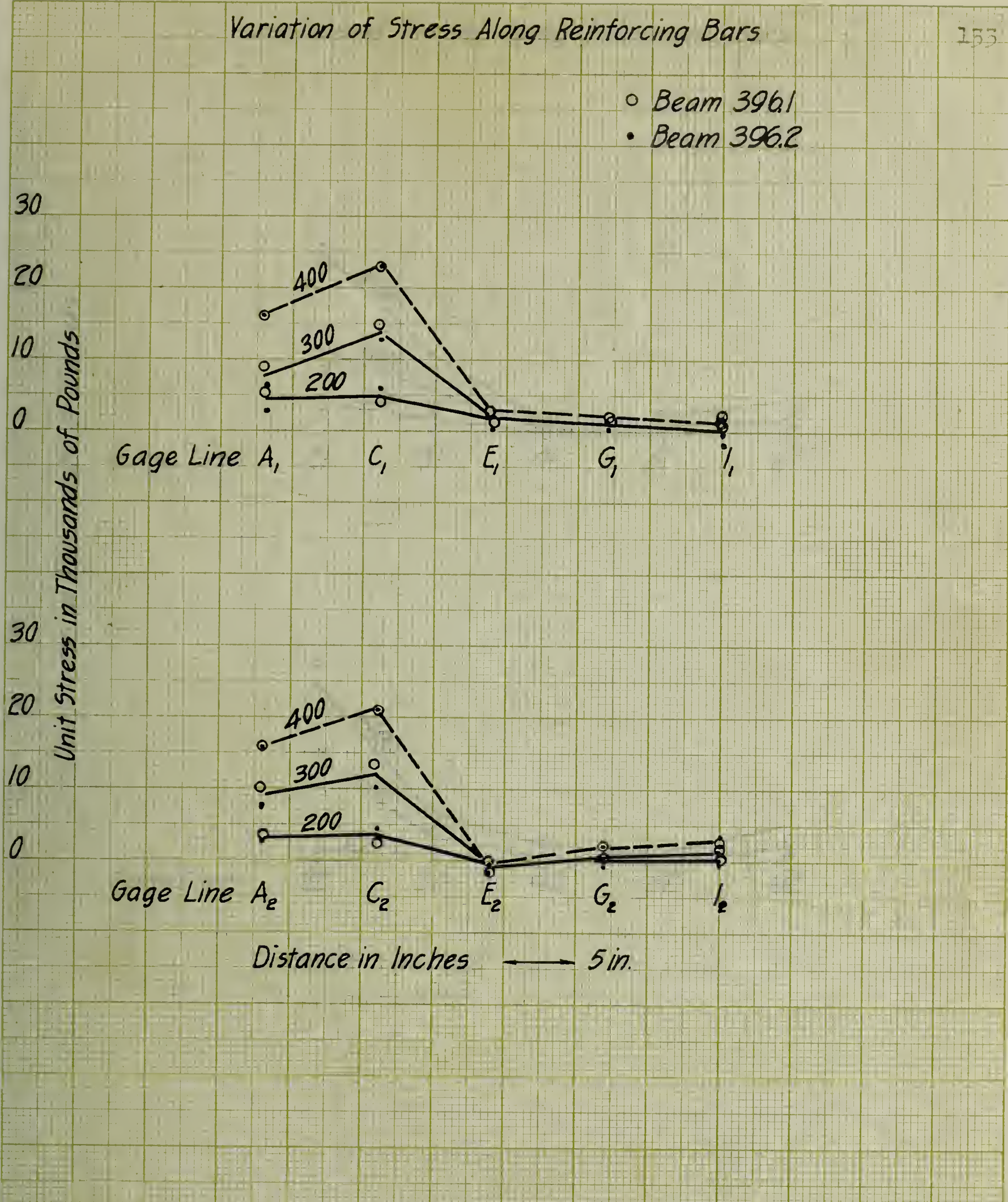
Variation of Stress Along Reinforcing Bars



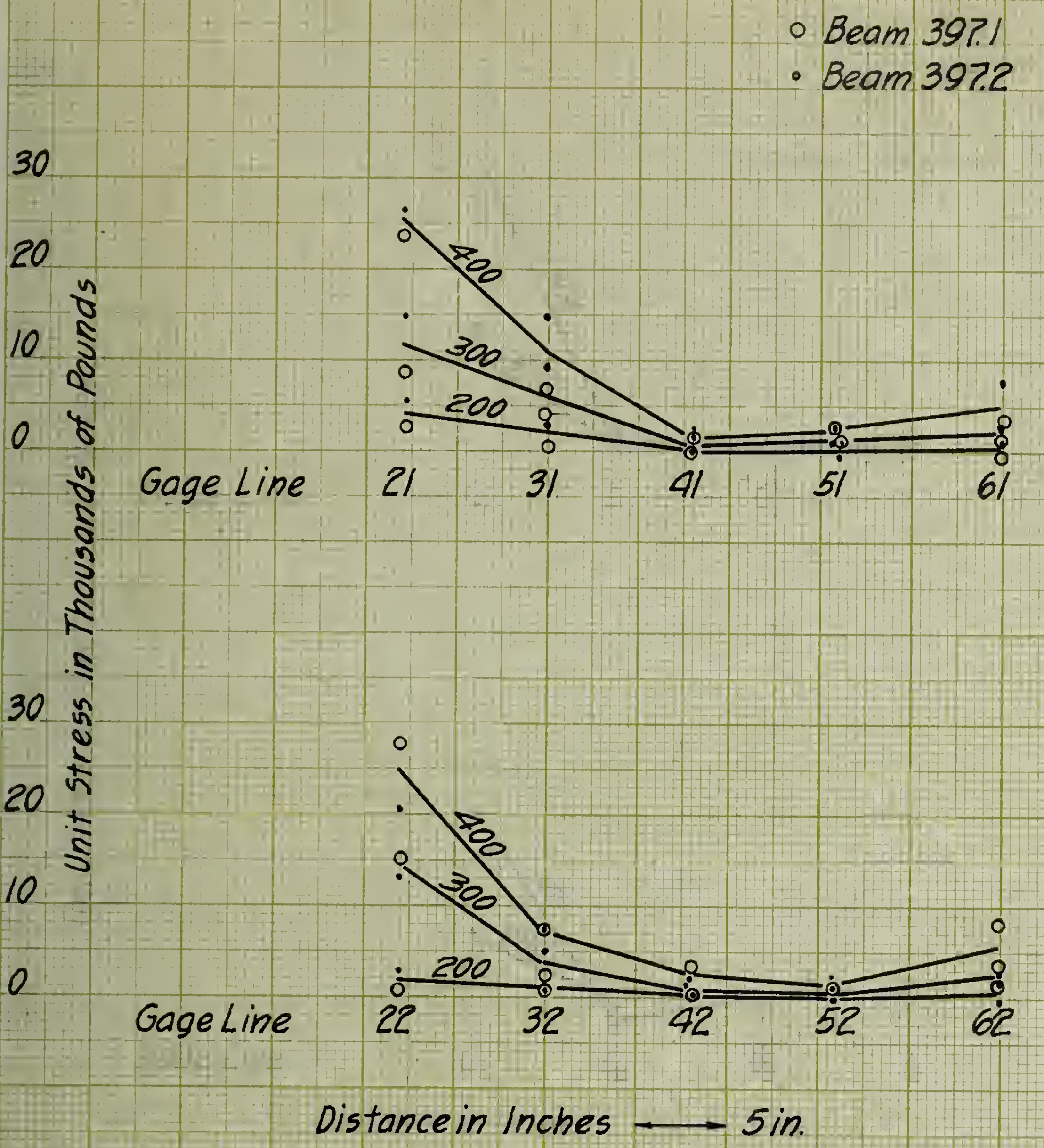

Variation of Stress Along Reinforcing Bars
○ Beam 394.1
• Beam 394.2
Unit Stress in Thousands of Pounds
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
40
30
20
10
0
400
300
200
Gage Line 22 32 42 52 62
30
20
10
0
400
300
200
Gage Line 23 33 43 53
Distance in Inches ←—→ 5 in.

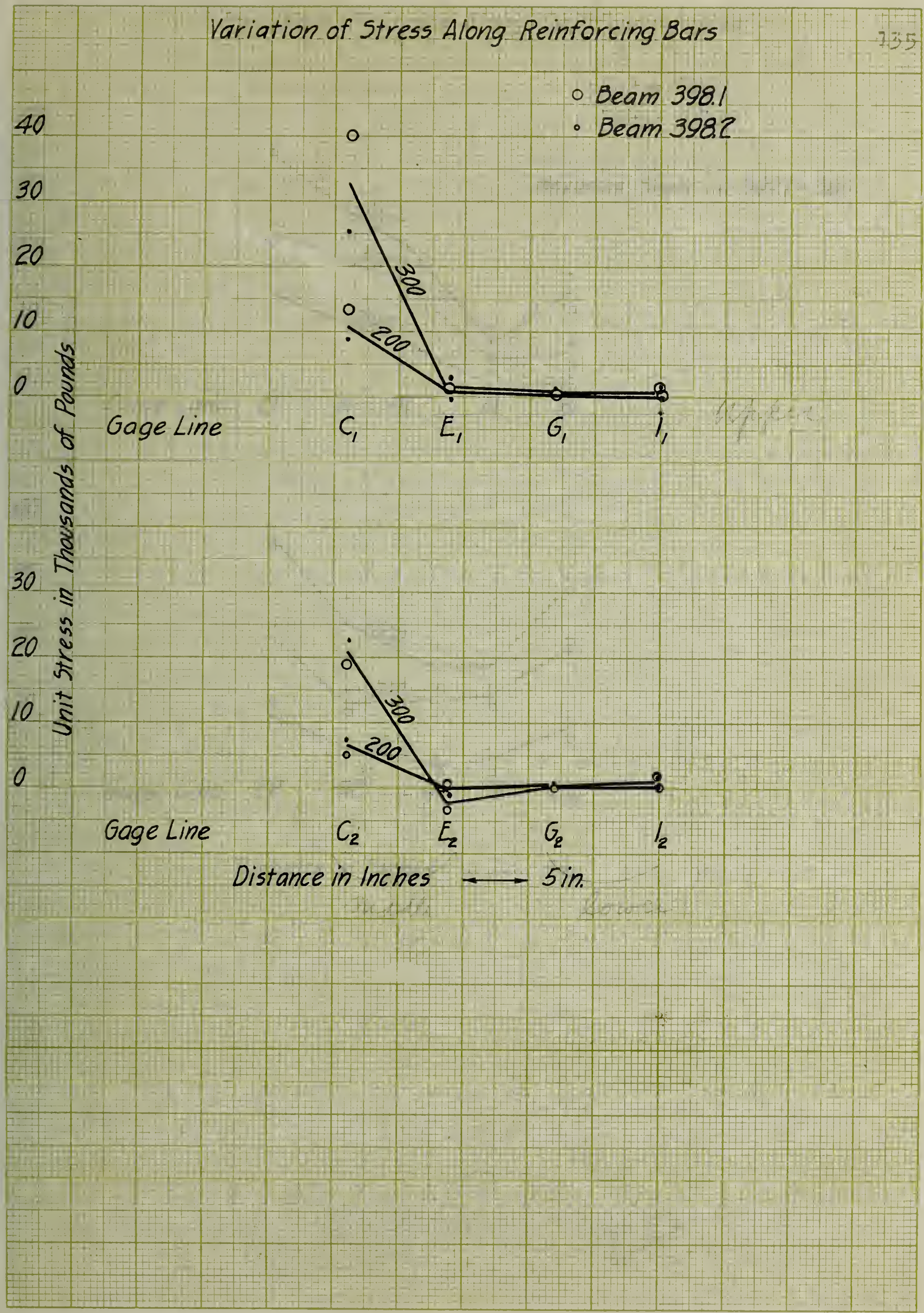
Variation of Stress Along Reinforcing Bars



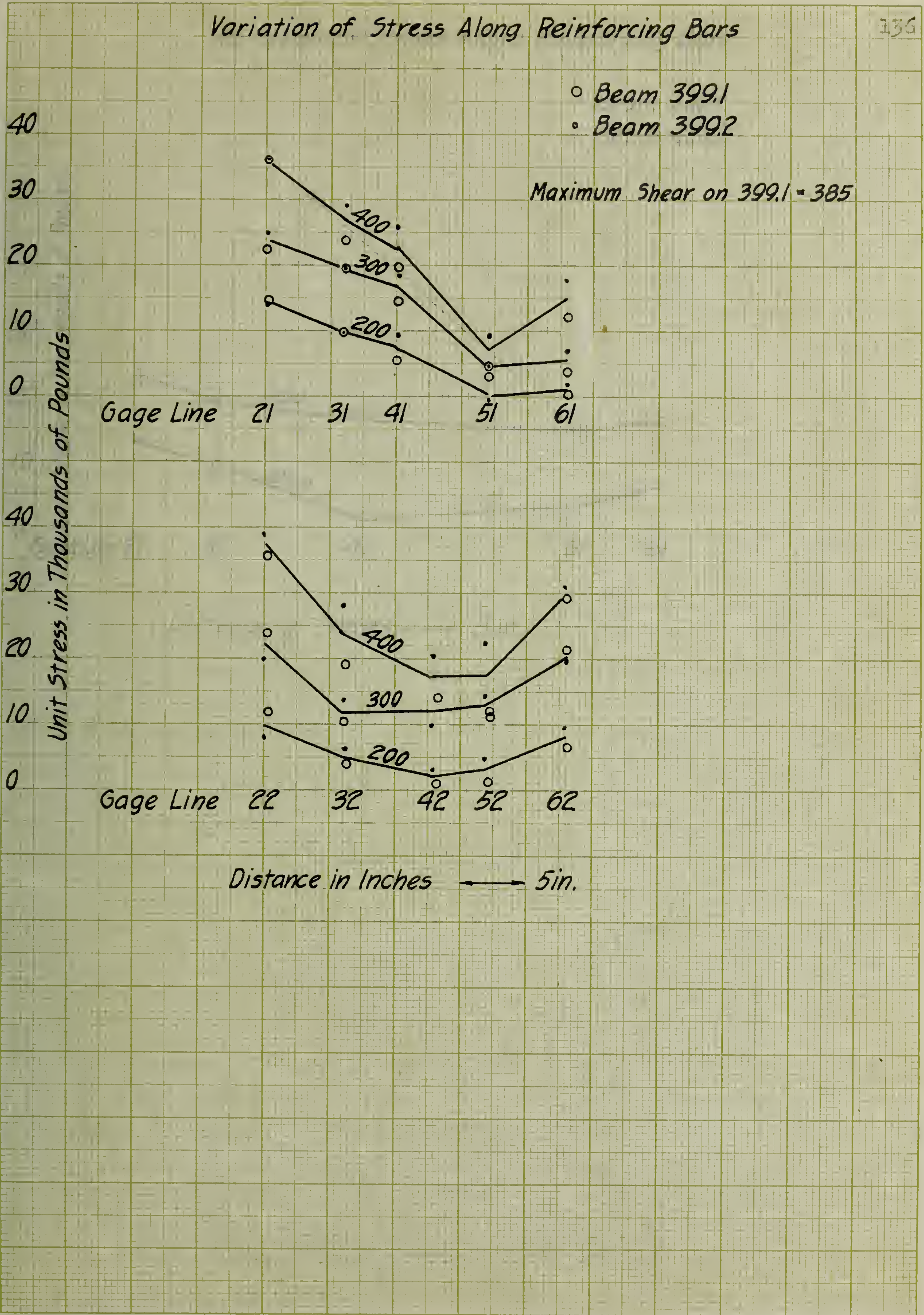

Variation of Stress Along Reinforcing Bars
○ Beam 396.1
• Beam 396.2
Unit Stress in Thousands of Pounds
30
20
10
0
400
300
200
Gage Line A1 C1 E1 G1 I1
30
20
10
0
400
300
200
Gage Line A2 C2 E2 G2 I2
Distance in Inches
5 in.

Variation of Stress Along Reinforcing Bars

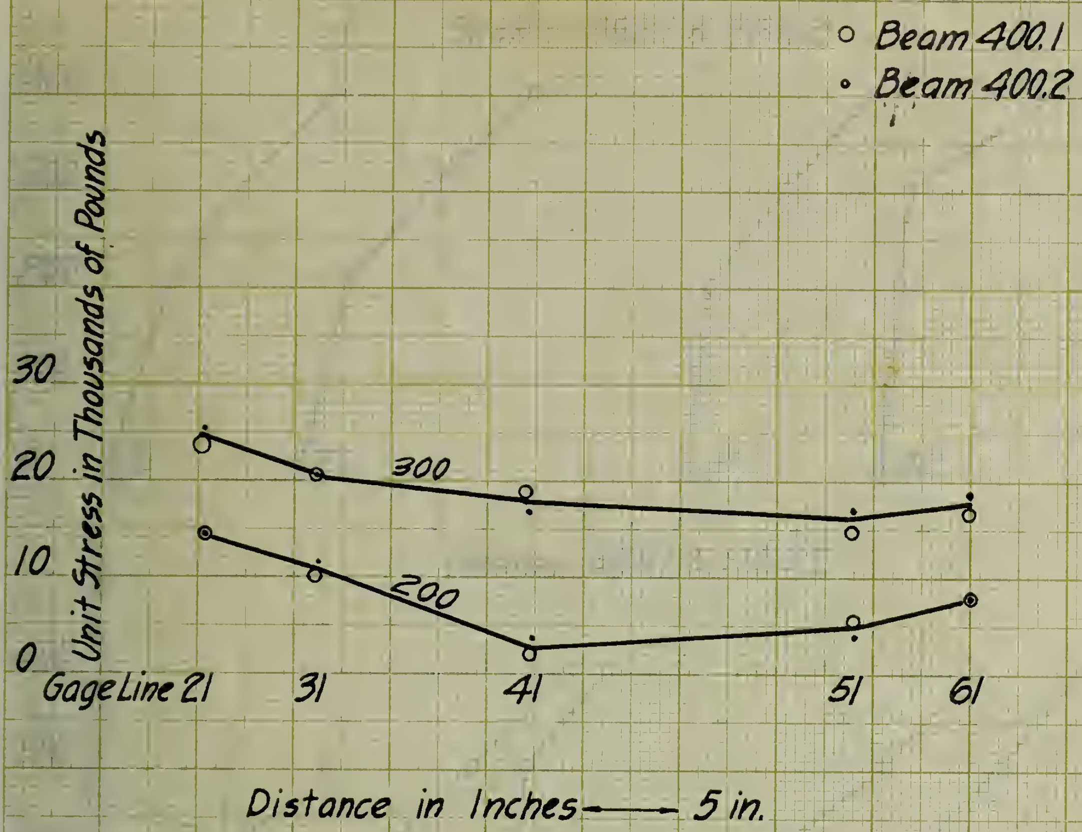


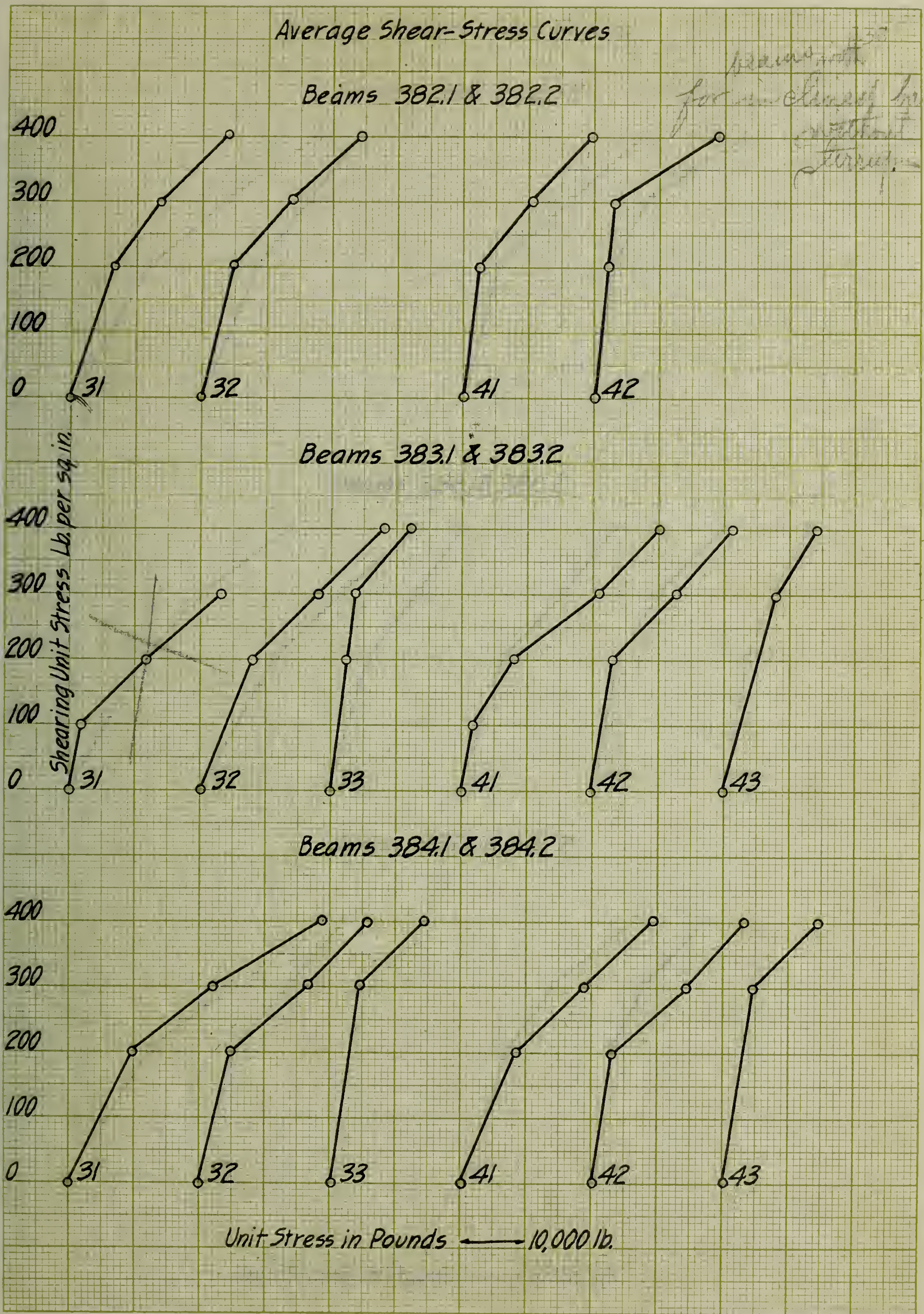


Variation of Stress Along Reinforcing Bars
○ Beam 398.1
• Beam 398.2
40
30
20
10
0
300
200
Gage Line
C1
E1
G1
I1
Unit Stress in Thousands of Pounds
30
20
10
0
300
200
Gage Line
C2
E2
G2
I2
Distance in Inches
5 in.

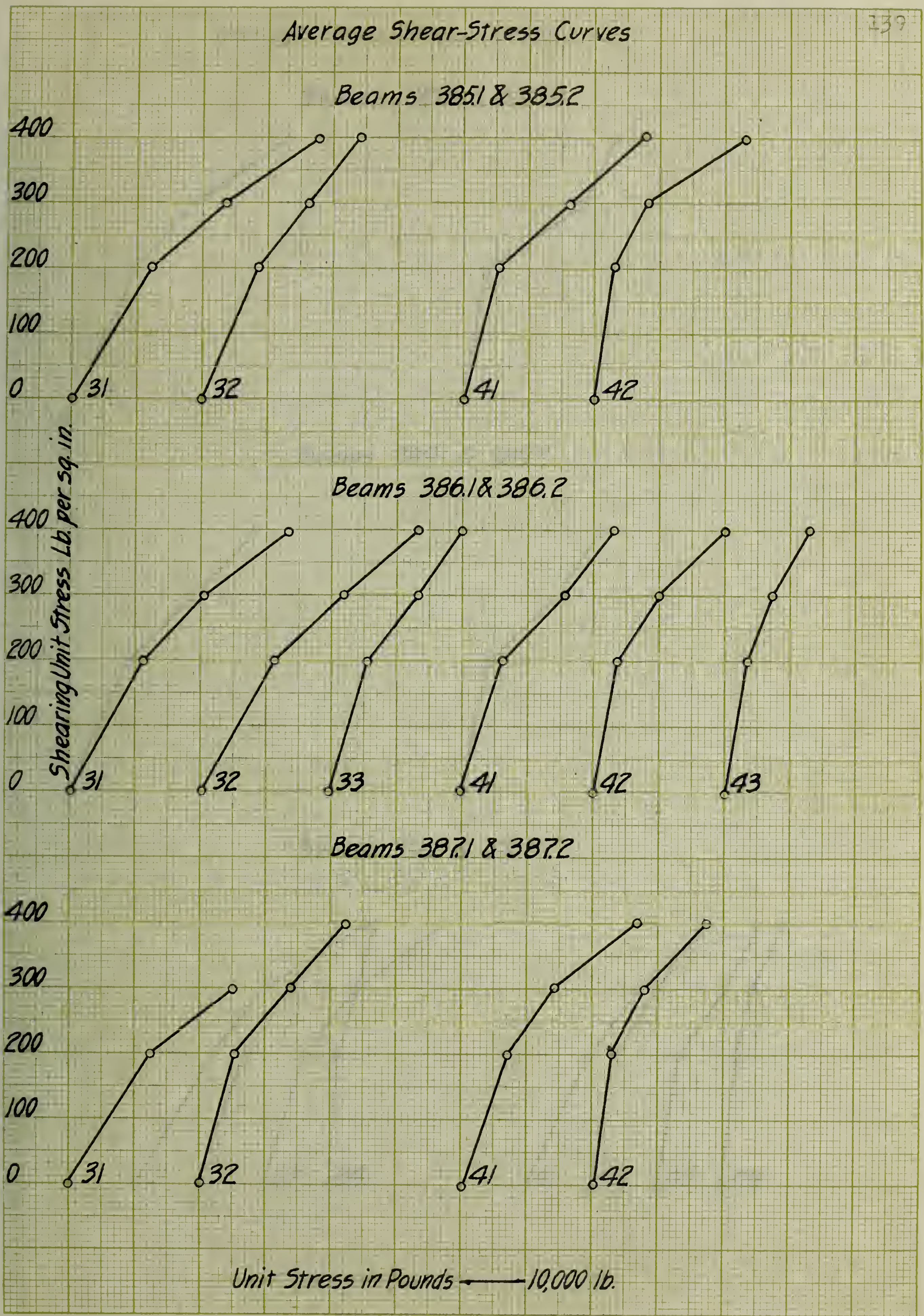

Variation of Stress Along Reinforcing Bars
○ Beam 399.1
• Beam 399.2
Maximum Shear on 399.1 = 385
Unit Stress in Thousands of Pounds
40
30
20
10
0
400
300
200
Gage Line 21 31 41 51 61
40
30
20
10
0
400
300
200
Gage Line 22 32 42 52 62
Distance in Inches ⟵⟶ 5in.

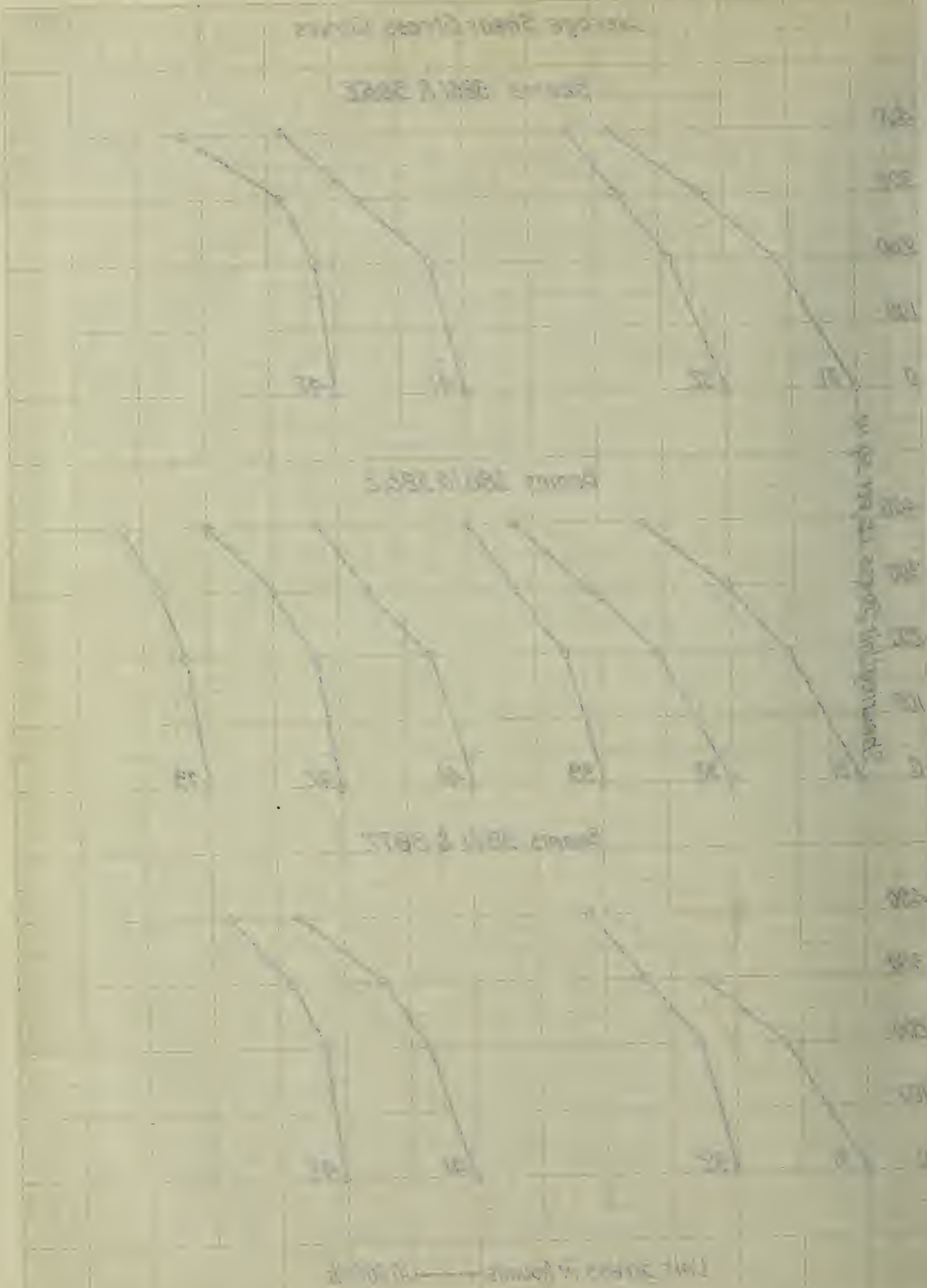
Variation of Stress Along Reinforcing Bars

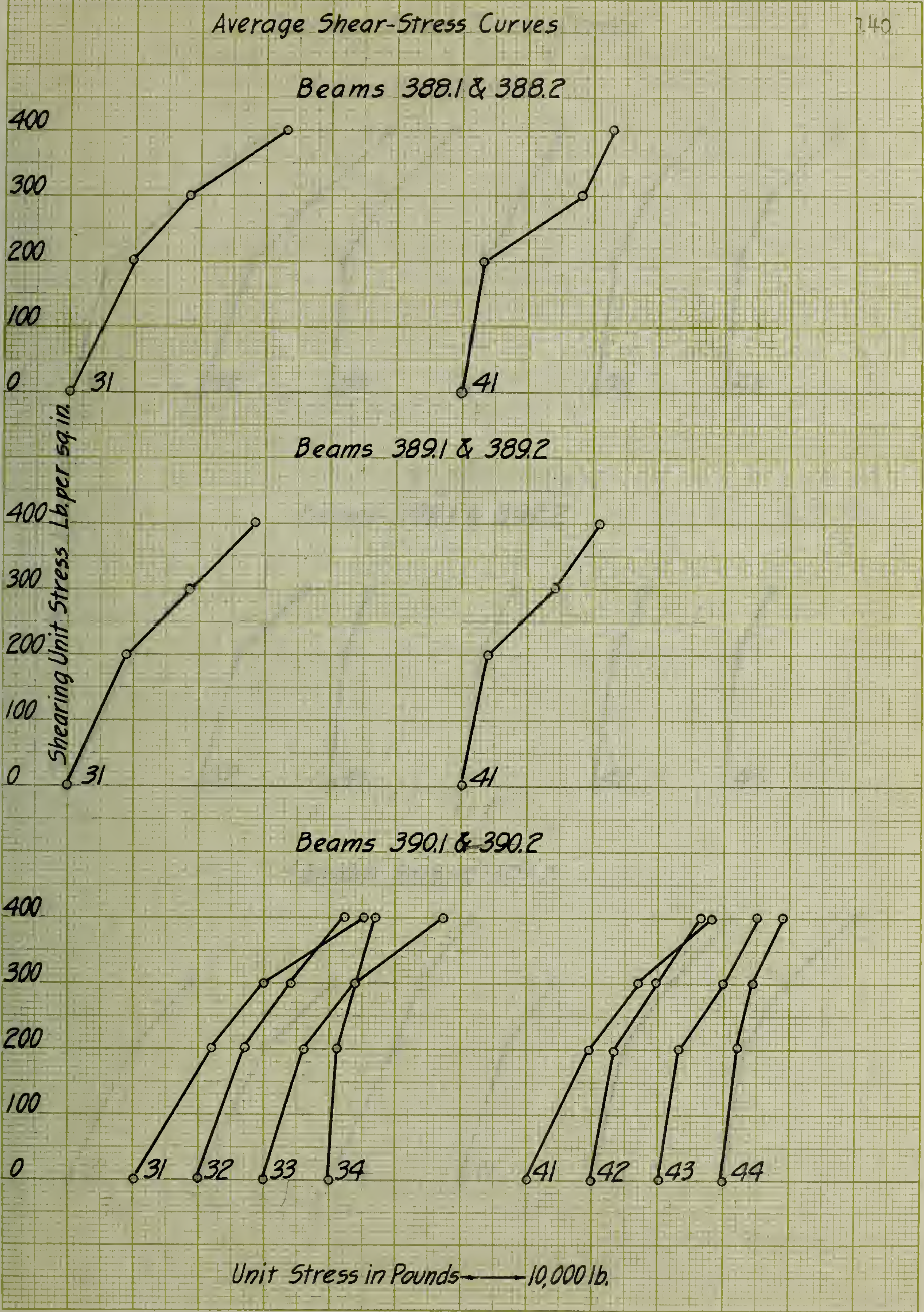


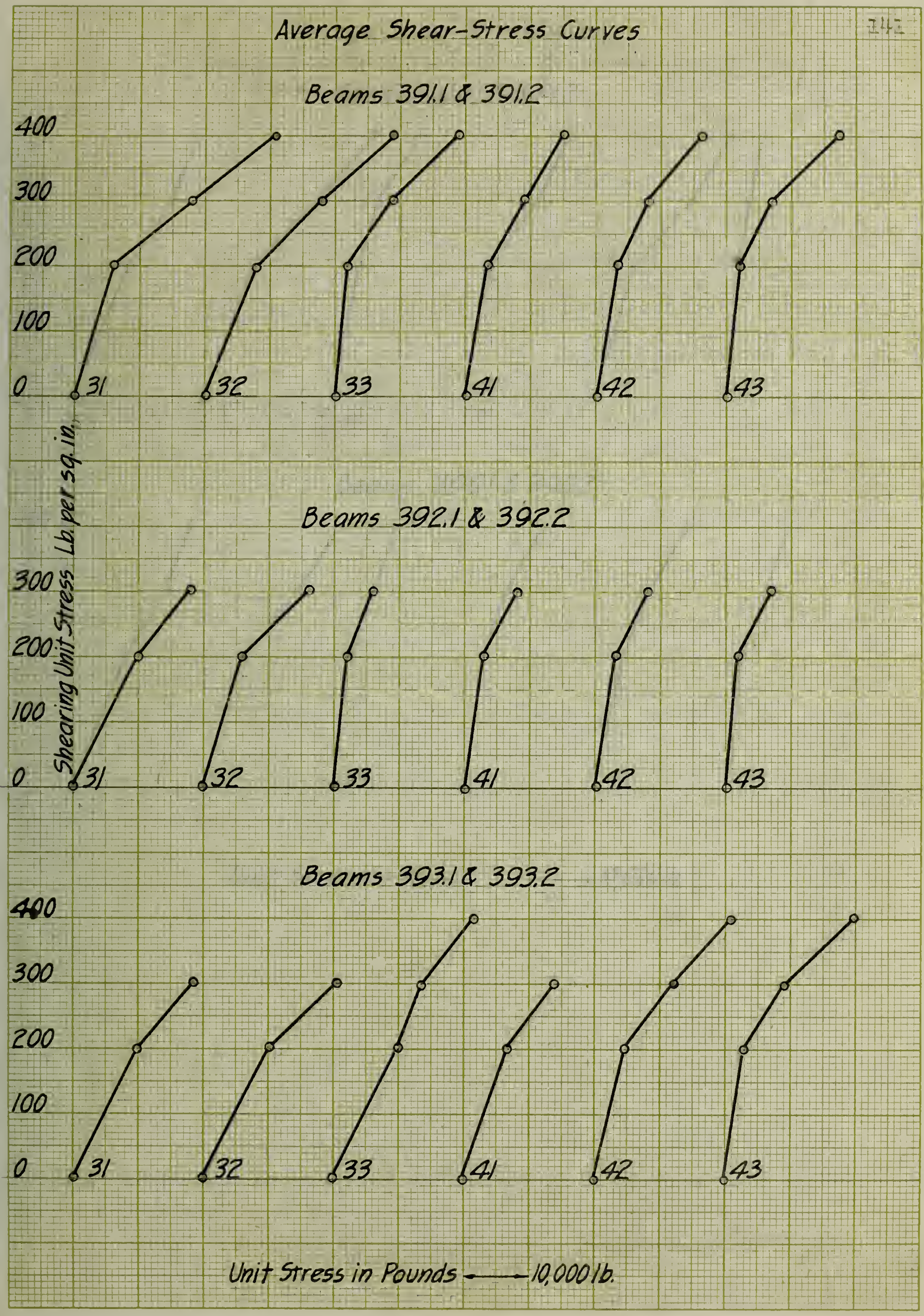


Average Shear-Stress Curves
Beams 382.1 & 382.2
Beams 383.1 & 383.2
Beams 384.1 & 384.2
Shearing Unit Stress Lb. per sq. in.
400
300
200
100
0
31
32
33
41
42
43
Unit Stress in Pounds ⟵⟶ 10,000 lb.

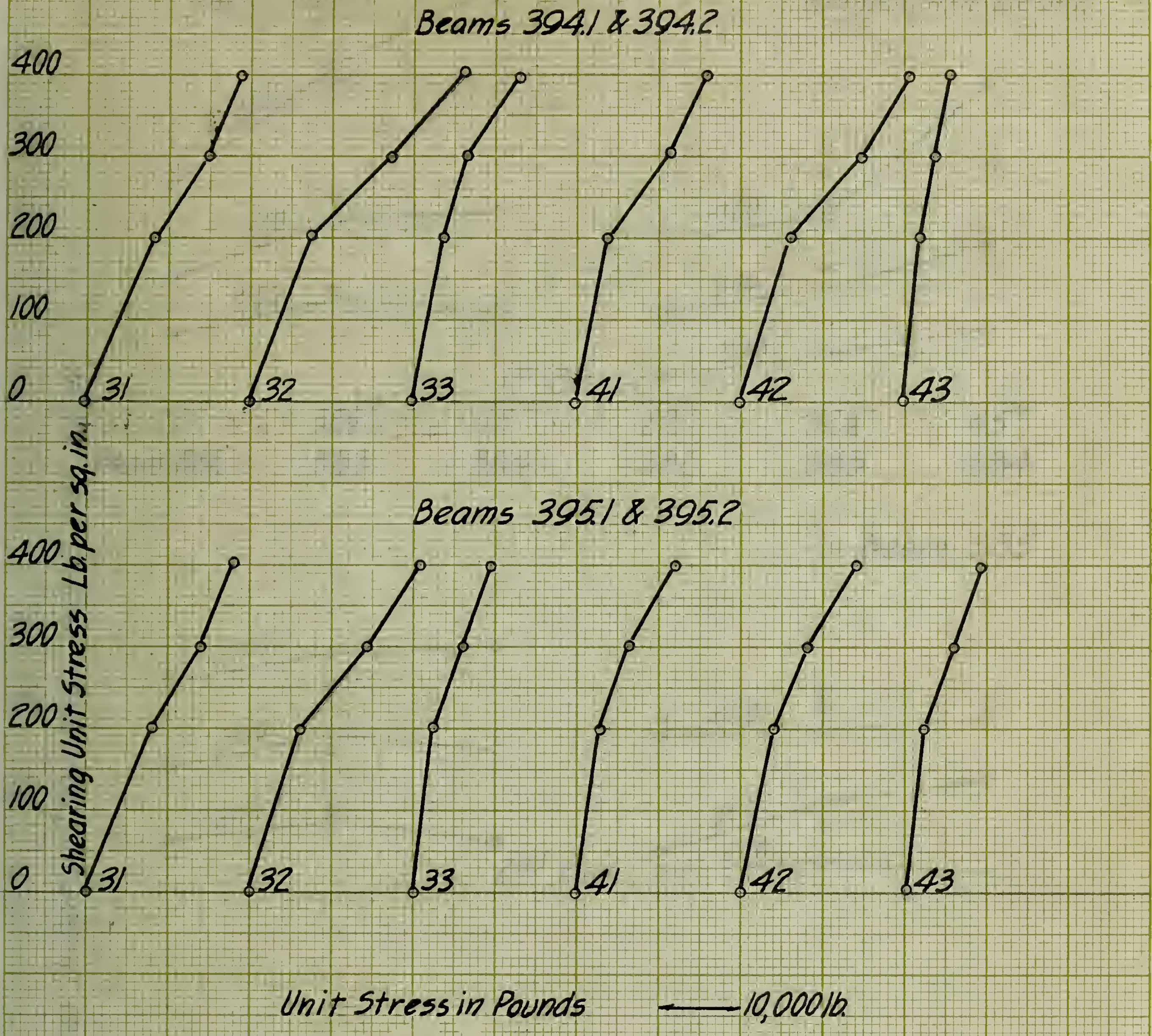

Average Shear-Stress Curves
Beams 385.1 & 385.2
Beams 386.1 & 386.2
Beams 387.1 & 387.2
400
300
200
100
0
31
32
33
41
42
43
Shearing Unit Stress Lb. per sq. in.
Unit Stress in Pounds ←——— 10,000 lb.

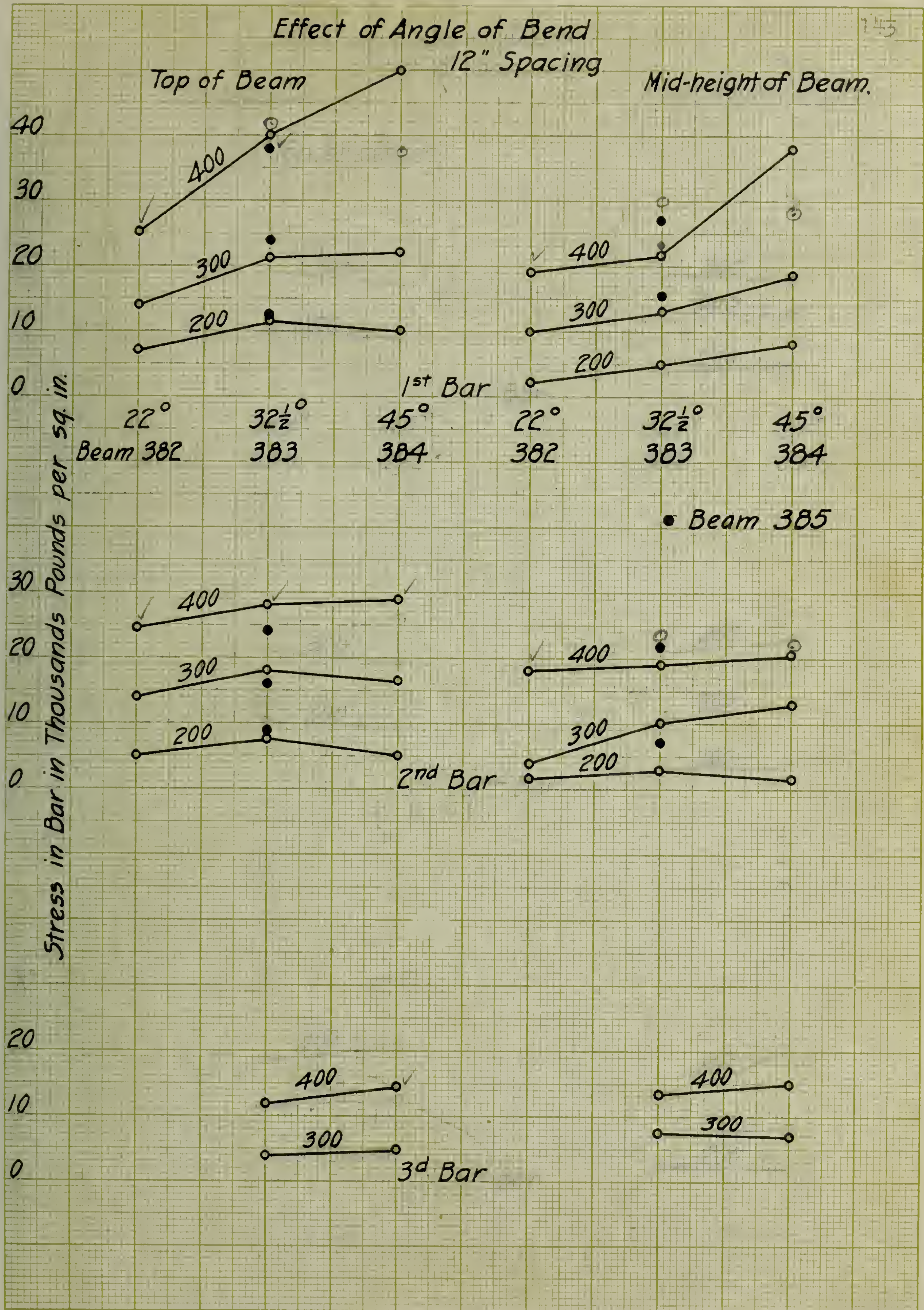



Average Shear-Stress Curves
Beams 388.1 & 388.2
400
300
200
100
0
31
41
Beams 389.1 & 389.2
400
300
200
100
0
31
41
Beams 390.1 & 390.2
400
300
200
100
0
31
32
33
34
41
42
43
44
Shearing Unit Stress Lb. per sq. in.
Unit Stress in Pounds ——— 10,000 lb.

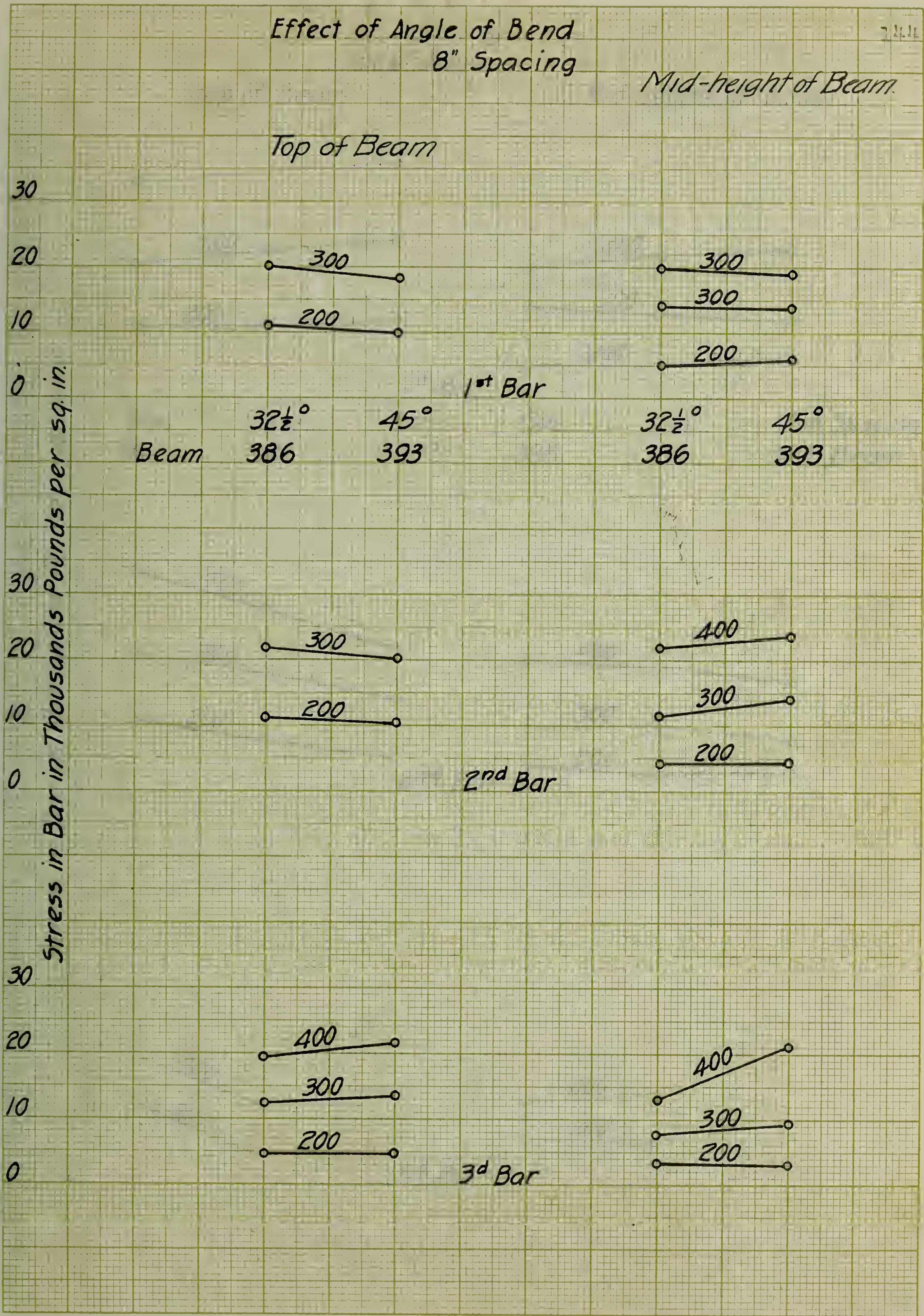

Average Shear-Stress Curves
Beams 391.1 & 391.2
400
300
200
100
0
31
32
33
41
42
43
Shearing Unit Stress Lb. per sq. in.
Beams 392.1 & 392.2
300
200
100
0
31
32
33
41
42
43
Beams 393.1 & 393.2
400
300
200
100
0
31
32
33
41
42
43
Unit Stress in Pounds ←——→ 10,000 lb.

Average Shear-Stress Curves

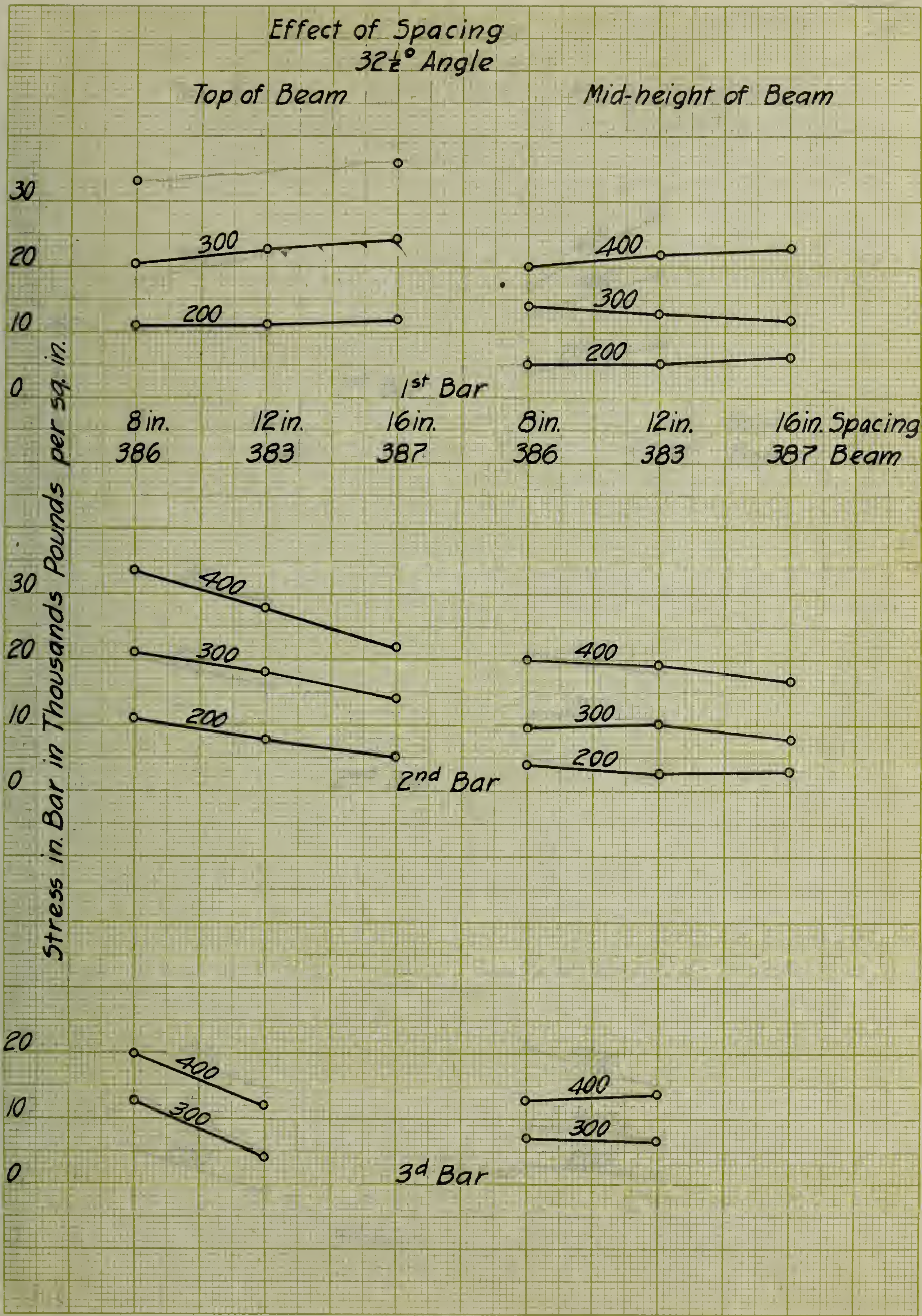




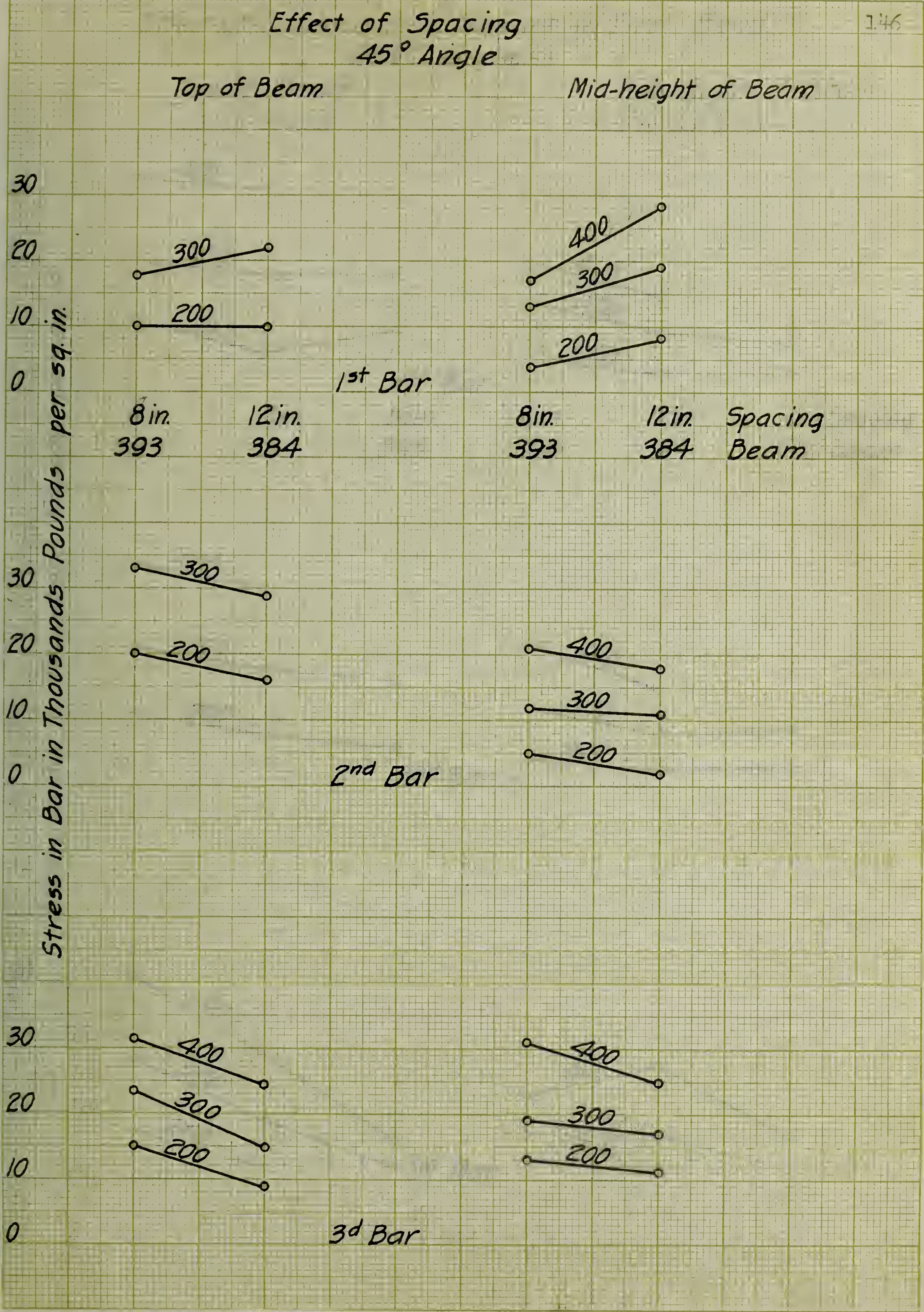
Effect of Angle of Bend
12" Spacing
Top of Beam
Mid-height of Beam.
Stress in Bar in Thousands Pounds per sq. in.
40
30
20
10
0
400
300
200
1st Bar
22°
32½°
45°
Beam 382
383
384
382
383
384
• Beam 385
2nd Bar
3d Bar



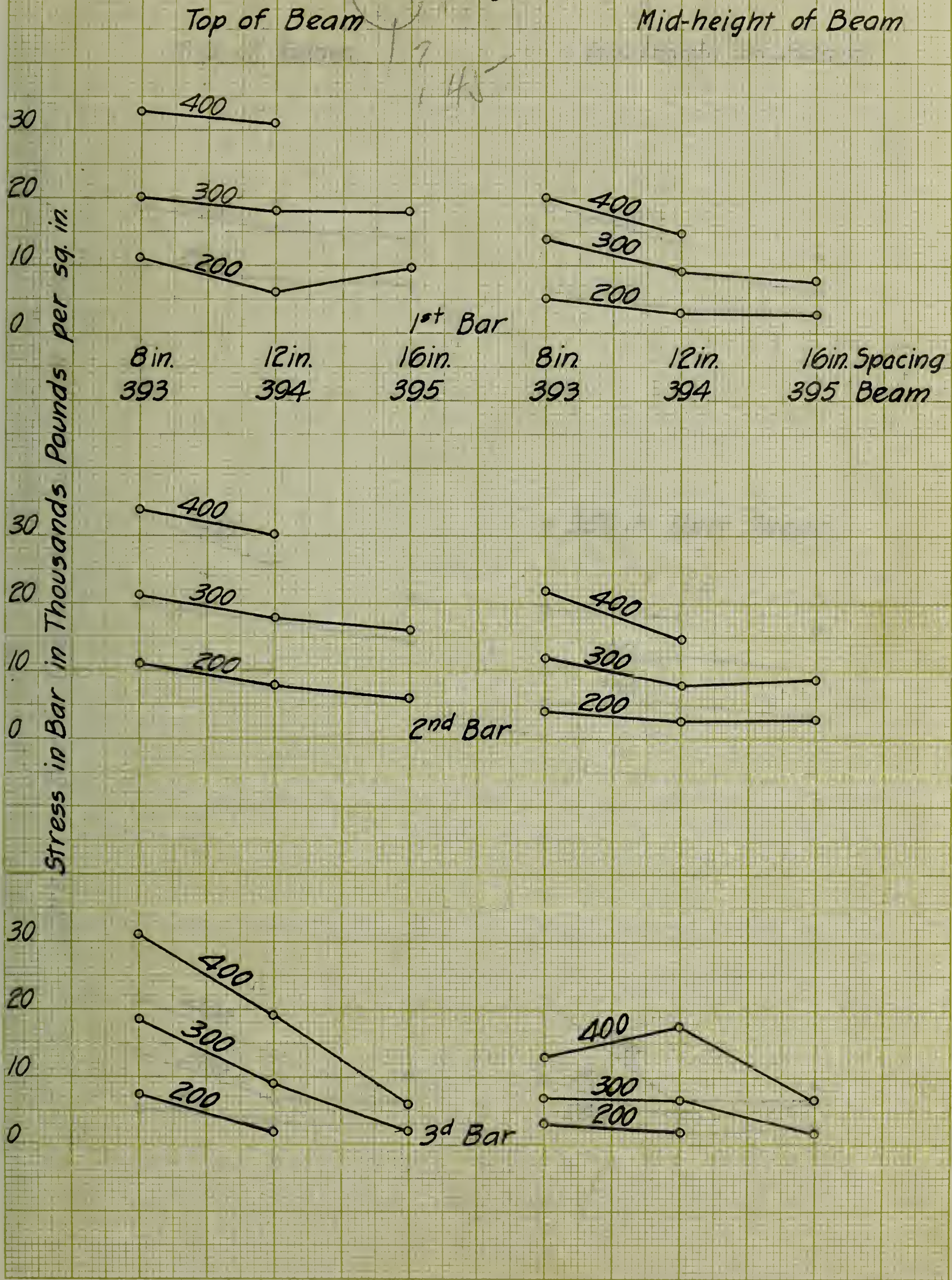
Effect of Angle of Bend
8" Spacing
Top of Beam
Mid-height of Beam
Stress in Bar in Thousands Pounds per sq. in.
30
20
10
0
300
200
300
300
200
1st Bar
32½°
45°
Beam
386
393
32½°
45°
386
393
30
20
10
0
300
200
400
300
200
2nd Bar
30
20
10
0
400
300
200
400
300
200
3d Bar

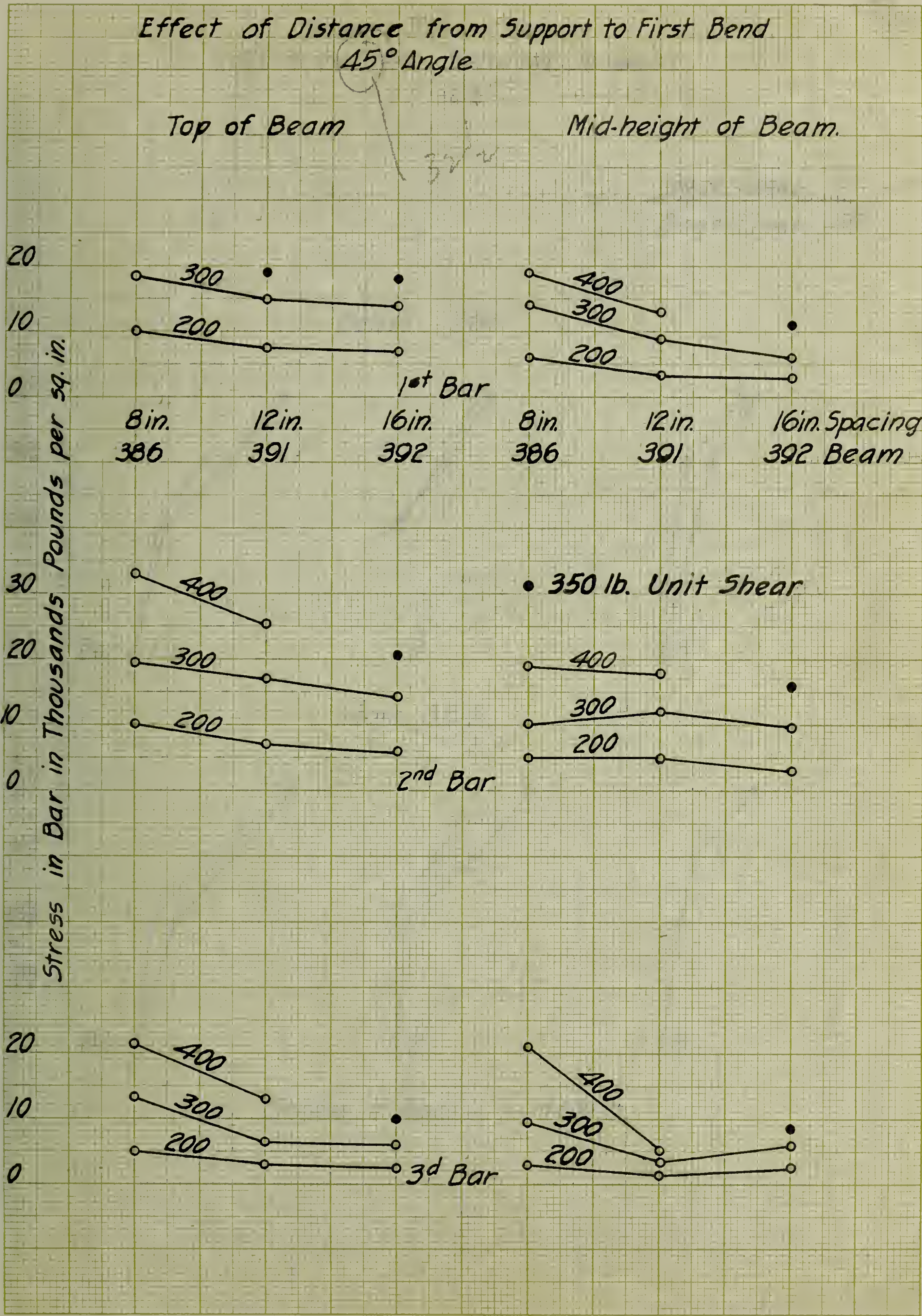


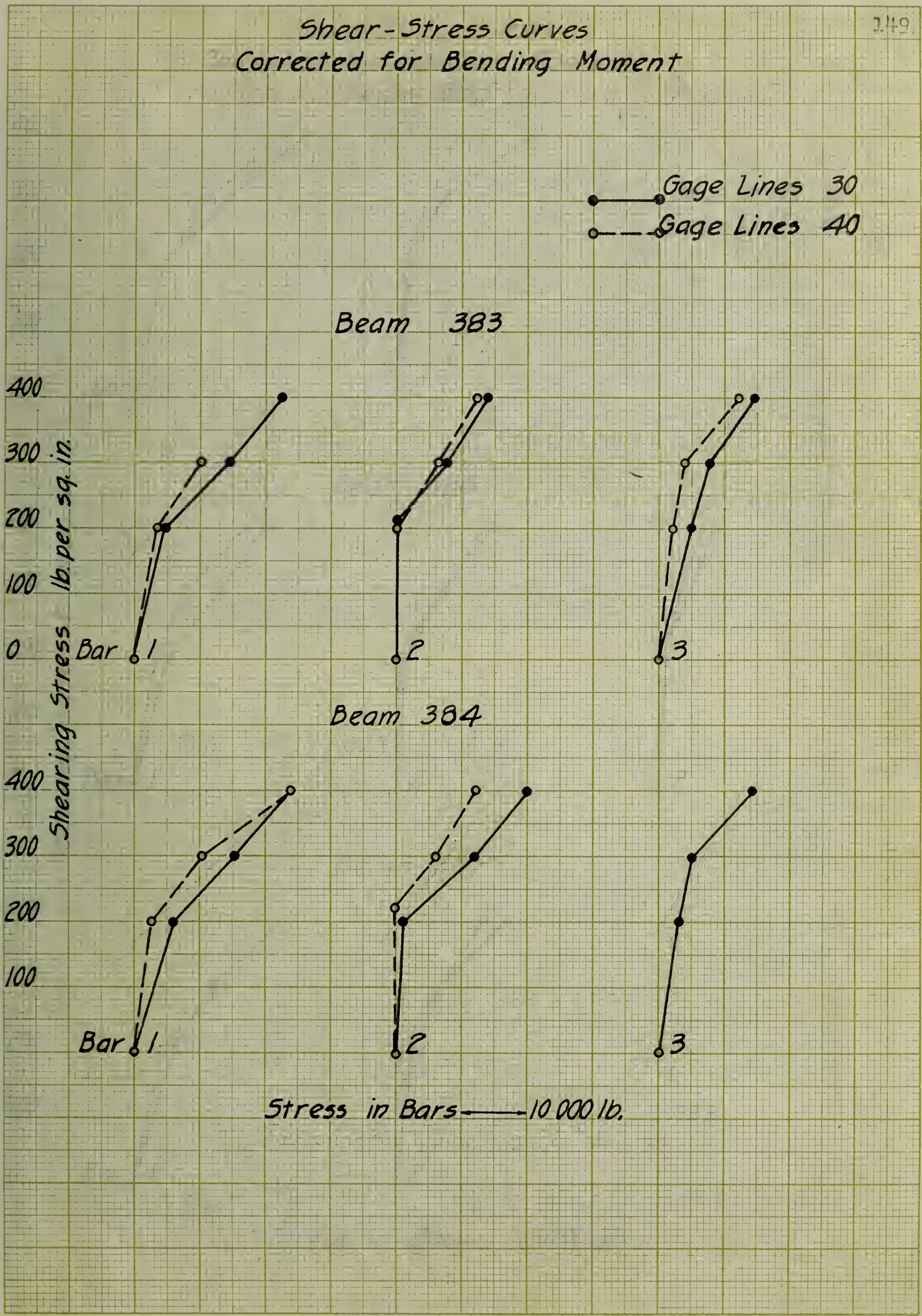
Effect of Spacing
32½° Angle
Top of Beam
Mid-height of Beam
Stress in Bar in Thousands Pounds per sq. in.
30
20
10
0
300
200
400
300
200
1st Bar
8 in.
386
12 in.
383
16 in.
387
8 in.
386
12 in.
383
16 in. Spacing
387 Beam
30
20
10
0
400
300
200
400
300
200
2nd Bar
20
10
0
400
300
400
300
3d Bar


Effect of Spacing
45° Angle
Top of Beam
Mid-height of Beam
Stress in Bar in Thousands Pounds per sq. in.
30
20
10
0
300
200
400
1st Bar
8 in.
12 in.
Spacing
393
384
Beam
2nd Bar
3d Bar

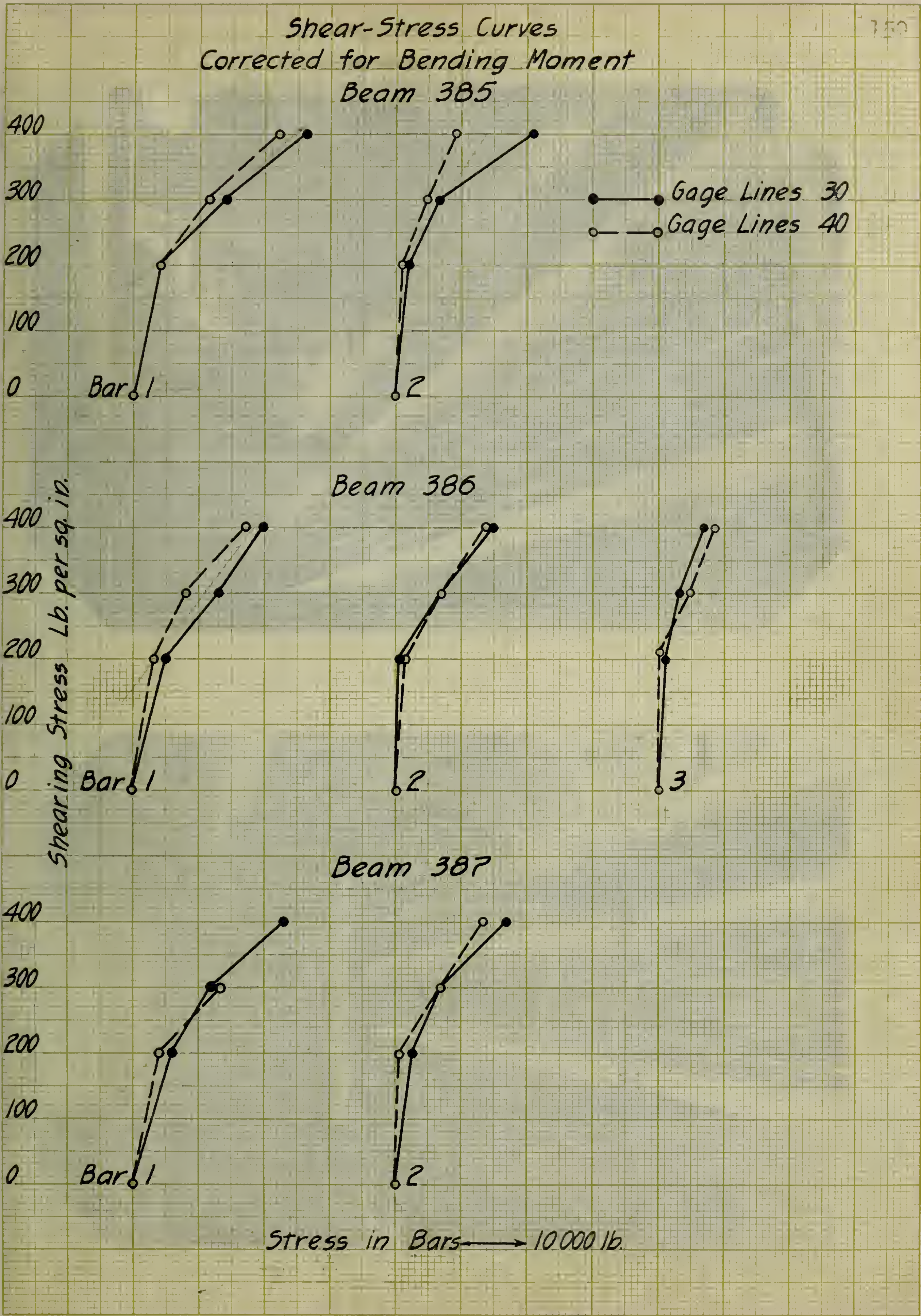
Effect of Distance from Support to First Bend.
(32½° Angle)

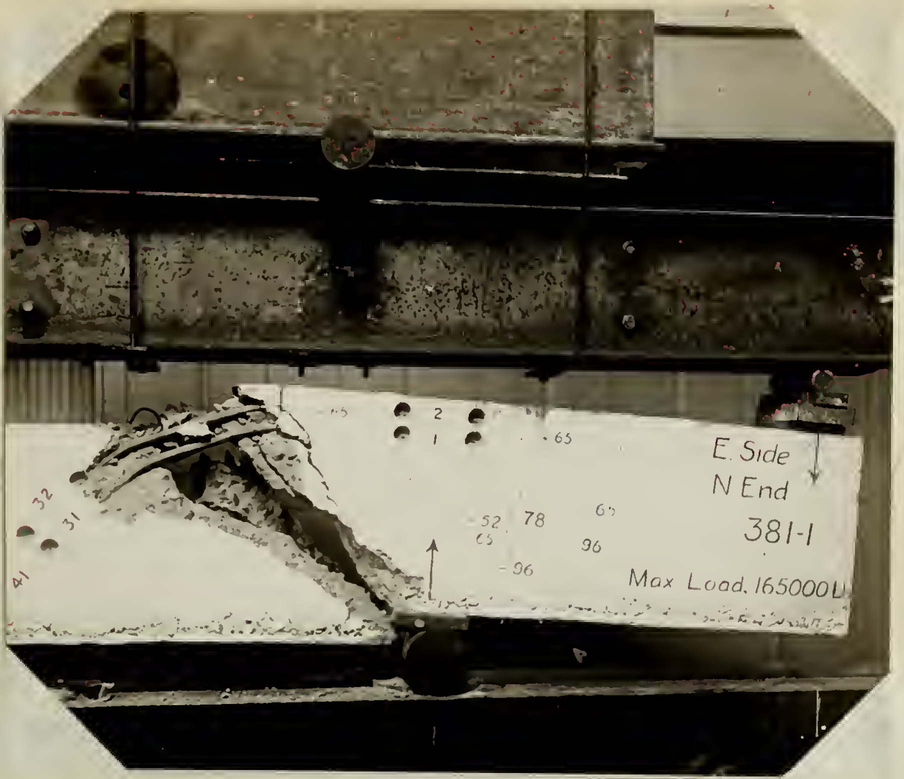



Effect of Distance from Support to First Bend
45° Angle
Top of Beam
Mid-height of Beam.
Stress in Bar in Thousands Pounds per sq. in.
1st Bar
2nd Bar
3d Bar
8 in.
12 in.
16 in.
16 in. Spacing
386
391
392
392 Beam
• 350 lb. Unit Shear
200
300
400
0
10
20
30



Shear-Stress Curves
Corrected for Bending Moment
Gage Lines 30
Gage Lines 40
Beam 383
400
300
200
100
0
Shearing Stress lb. per sq. in.
Bar 1
2
3
Beam 384
400
300
200
100
Bar 1
2
3
Stress in Bars ——— 10 000 lb.


Shear-Stress Curves
Corrected for Bending Moment
Beam 385
Beam 386
Beam 387
Gage Lines 30
Gage Lines 40
Shearing Stress Lb. per sq. in.
400
300
200
100
0
Bar 1
2
3
Stress in Bars → 10 000 lb.


E. Side
N End
381-1
Max Load. 165000

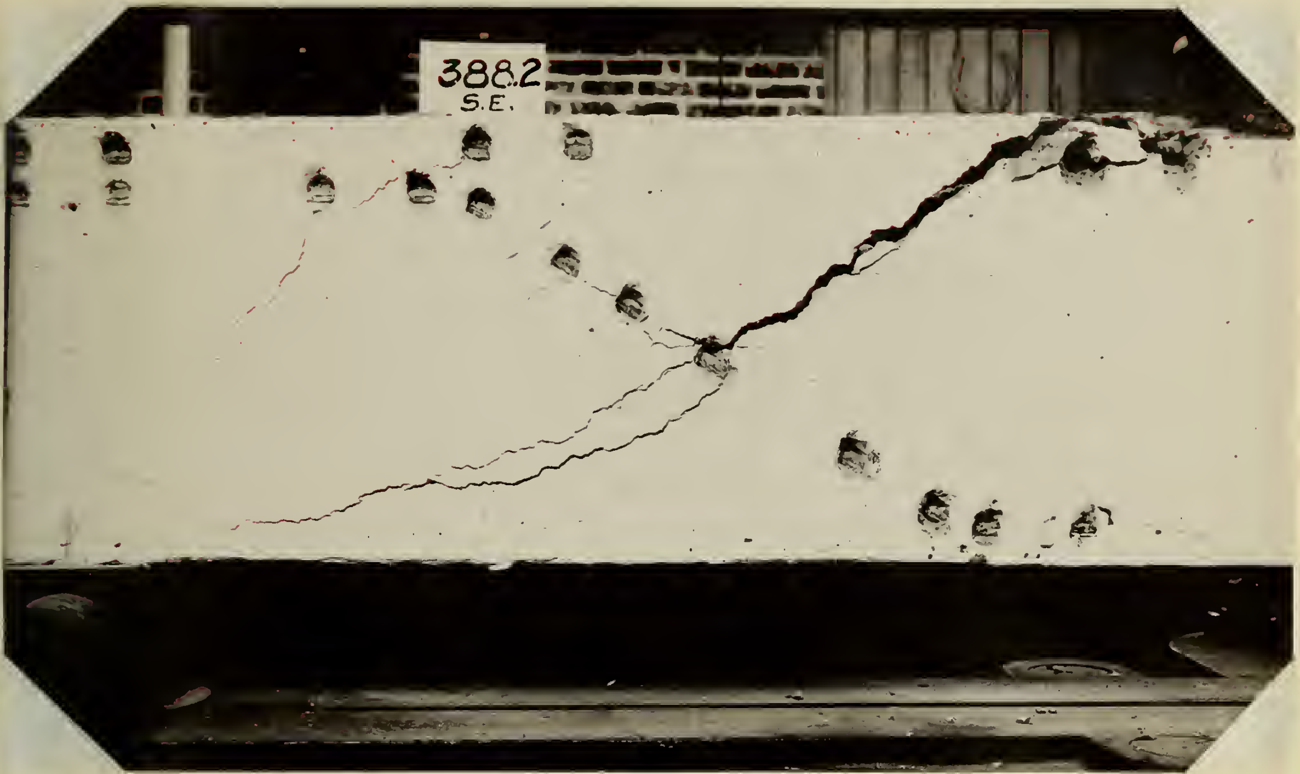

382-2
N.-E.

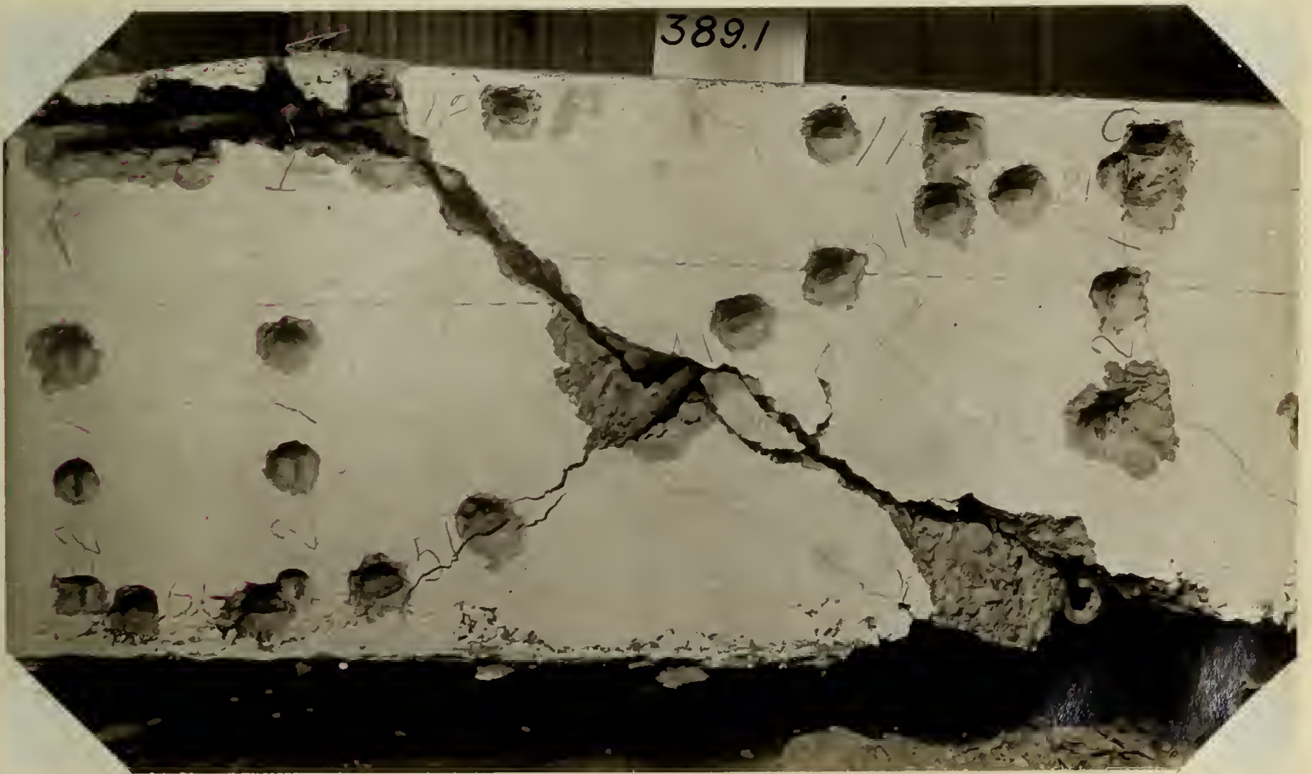

383.2
N-E


384.2
N-E


385.2
center

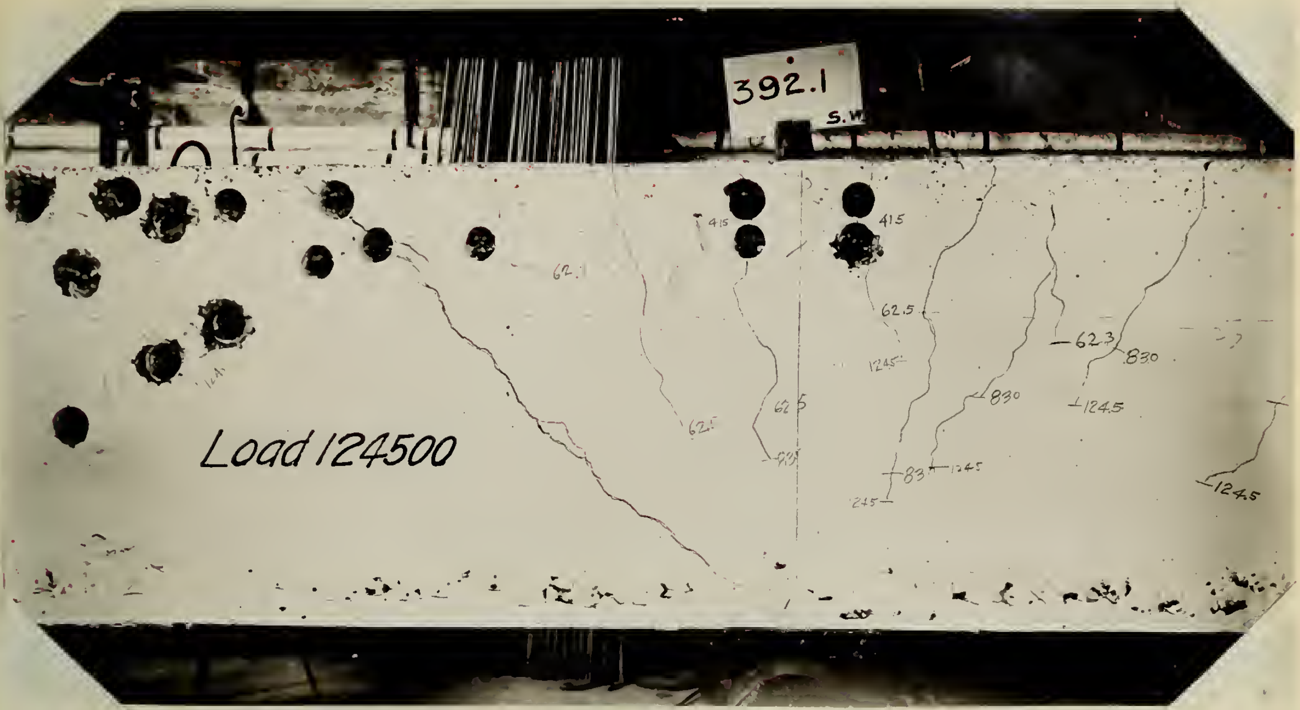

386.2
S.E.


388.2
S.E.

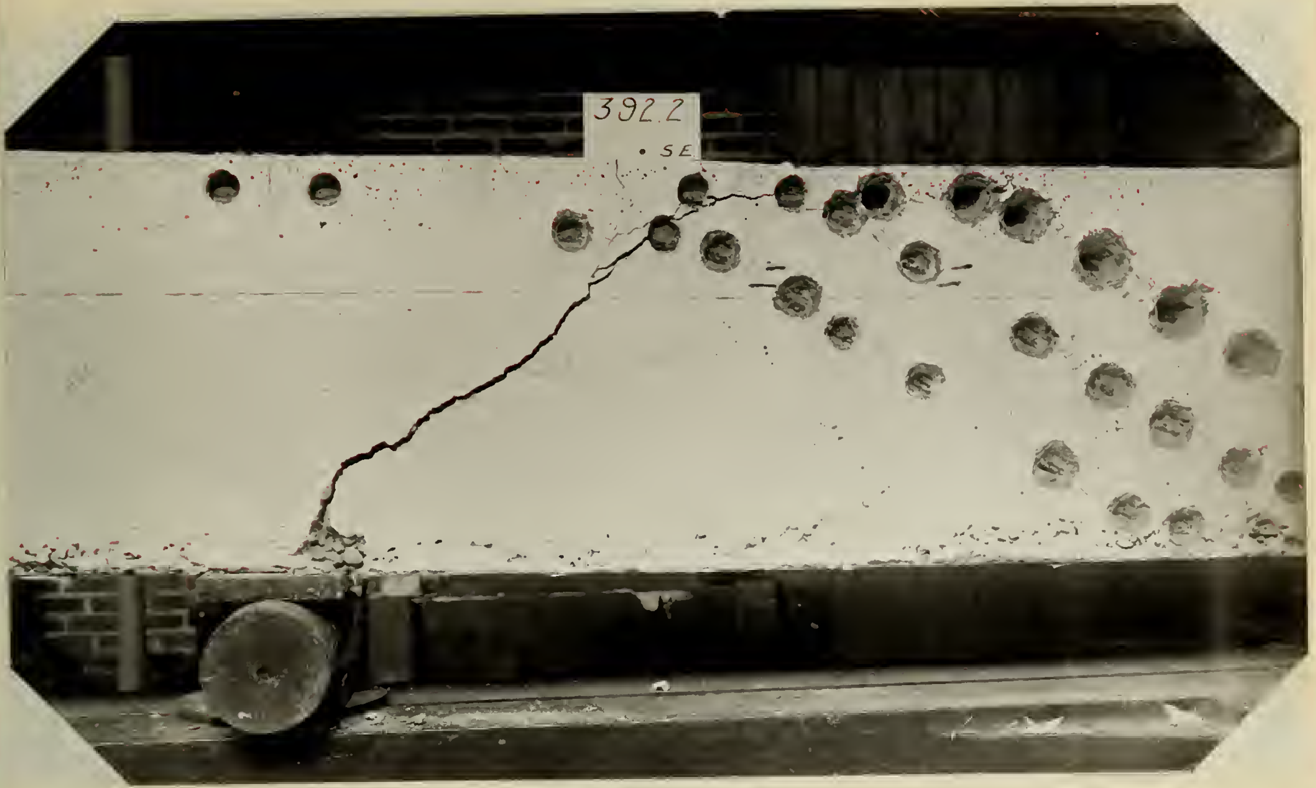

389.1


390.1


390.1


392.1
S.W.
Load 124500
62.1
62.5
62.3
83.0
124.5


392.1
S.W.
415
62.5

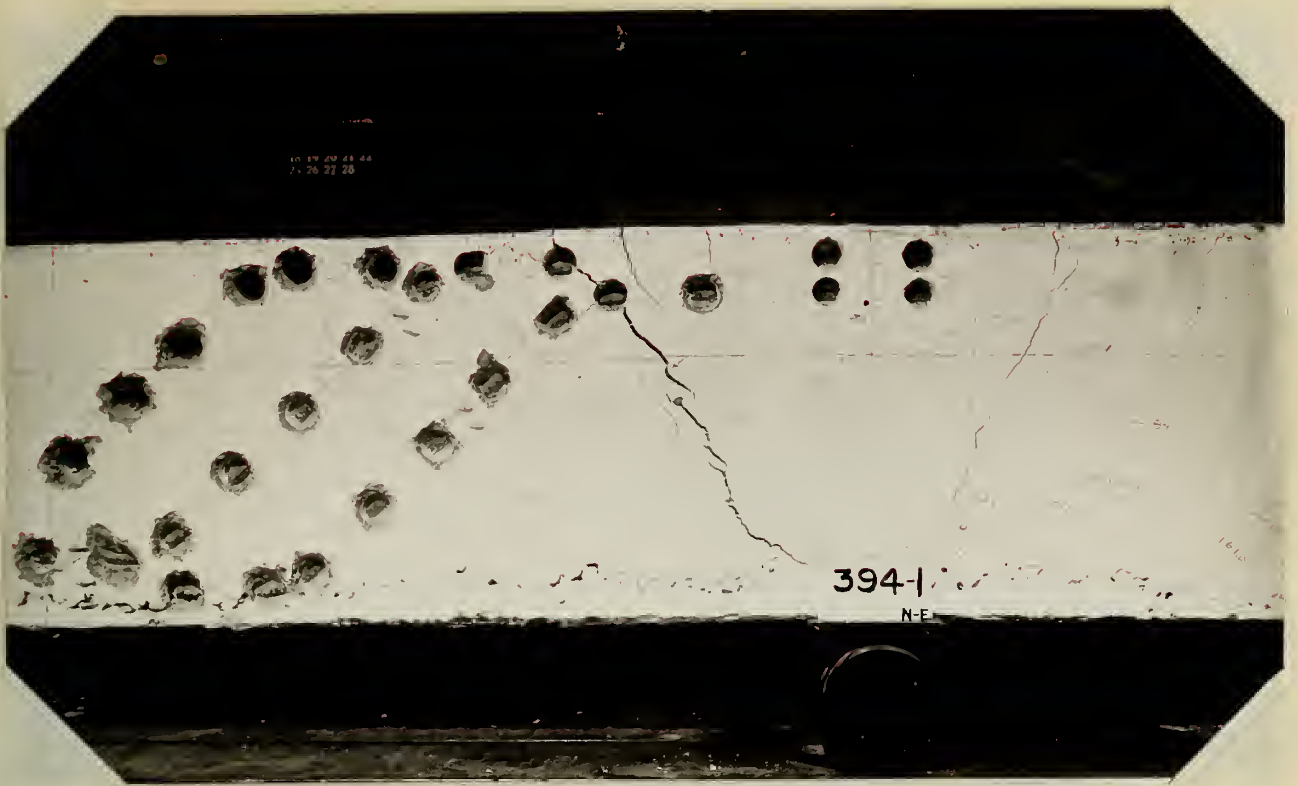


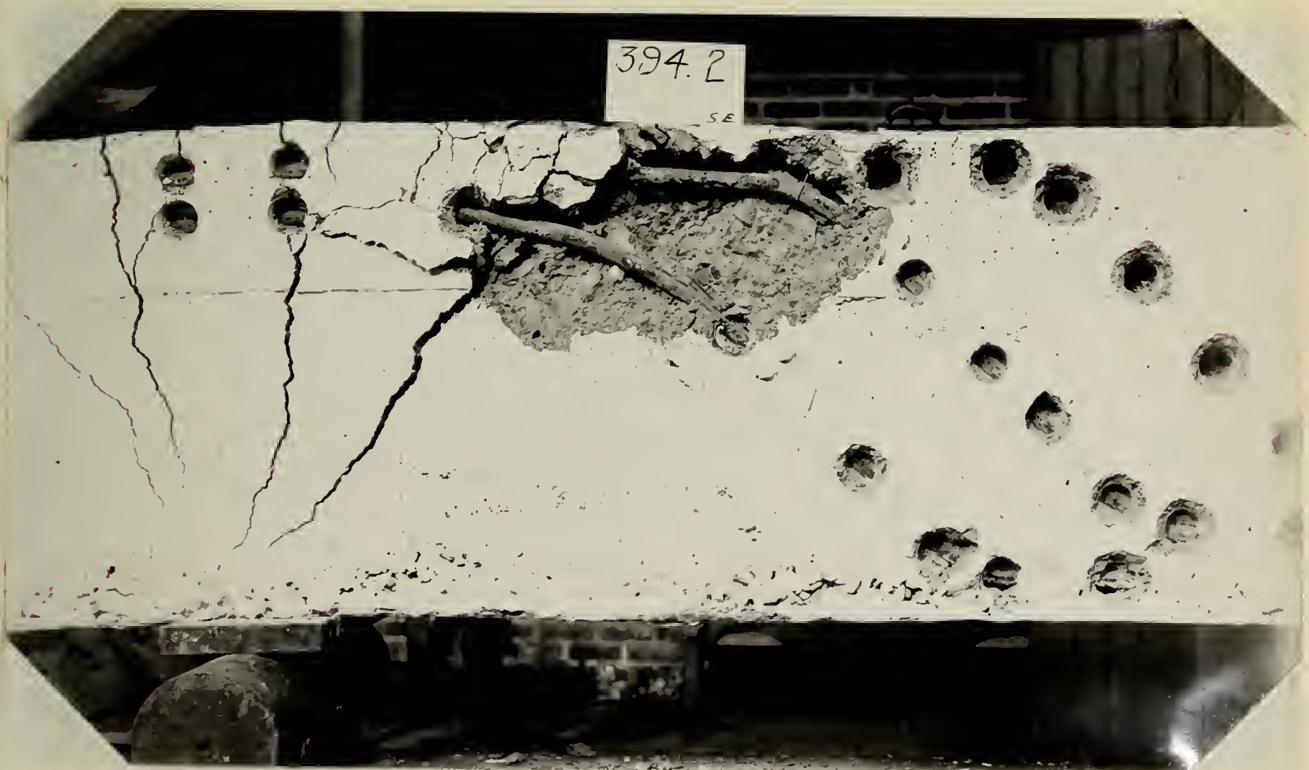
392.2
SE

392.2
NE


393-2
N.E


394-1
E. Side.
N. End.
Max Load 172,300 Lb


394-1
N-E


394. 2
SE

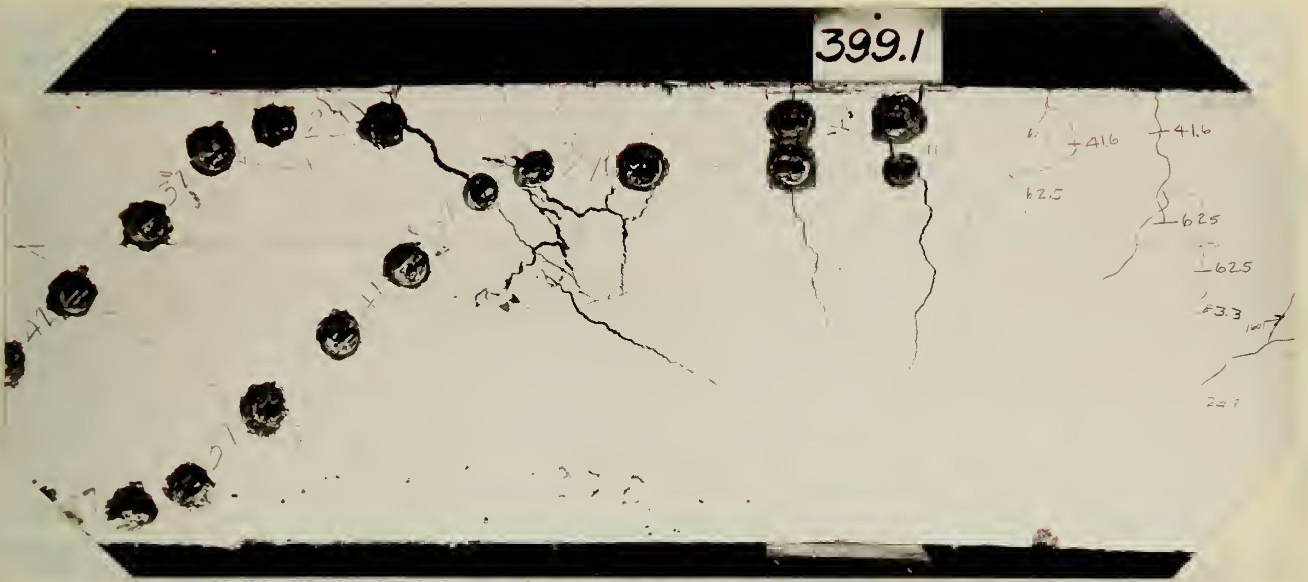

395.1

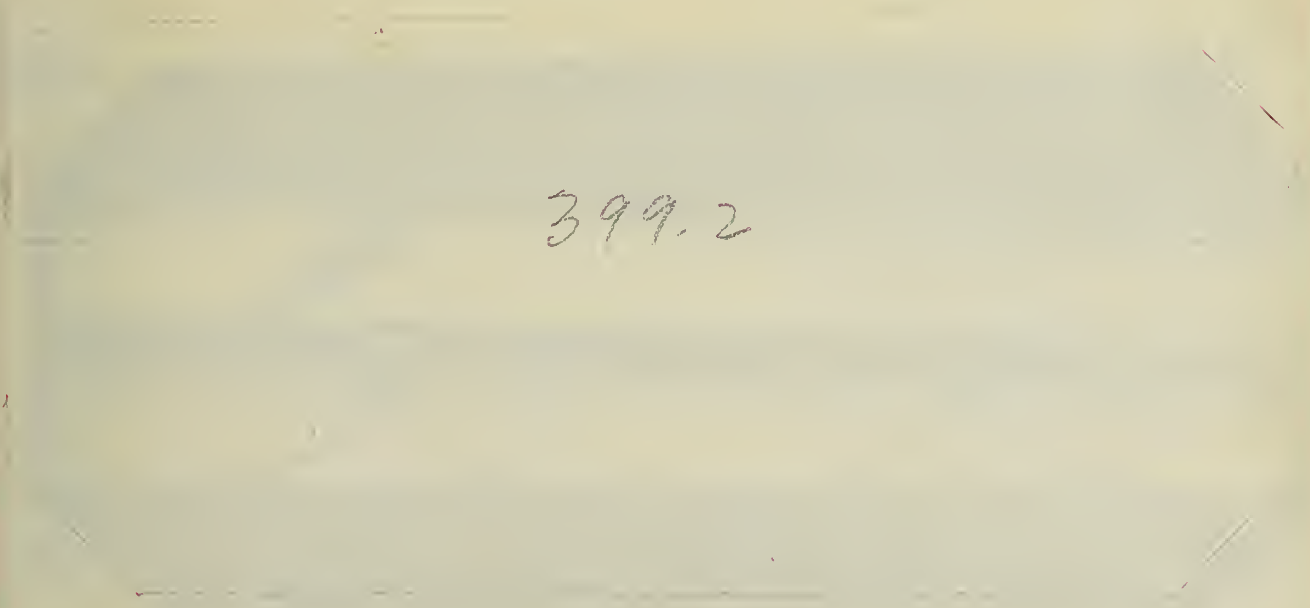

395.1

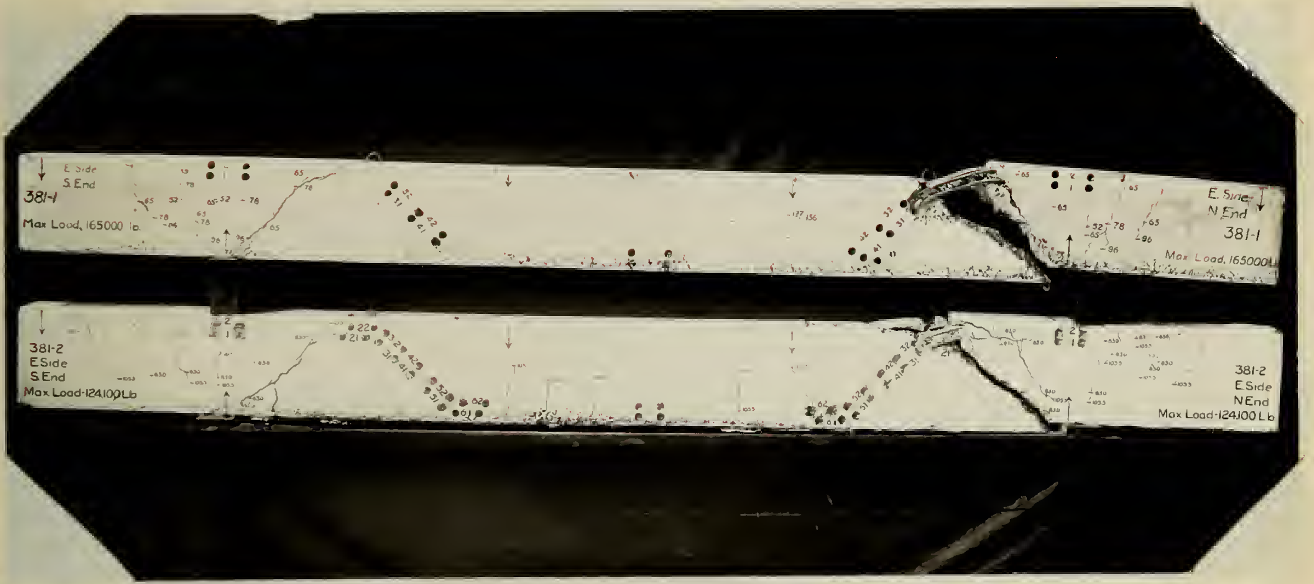

396.2
N.E.


398.1

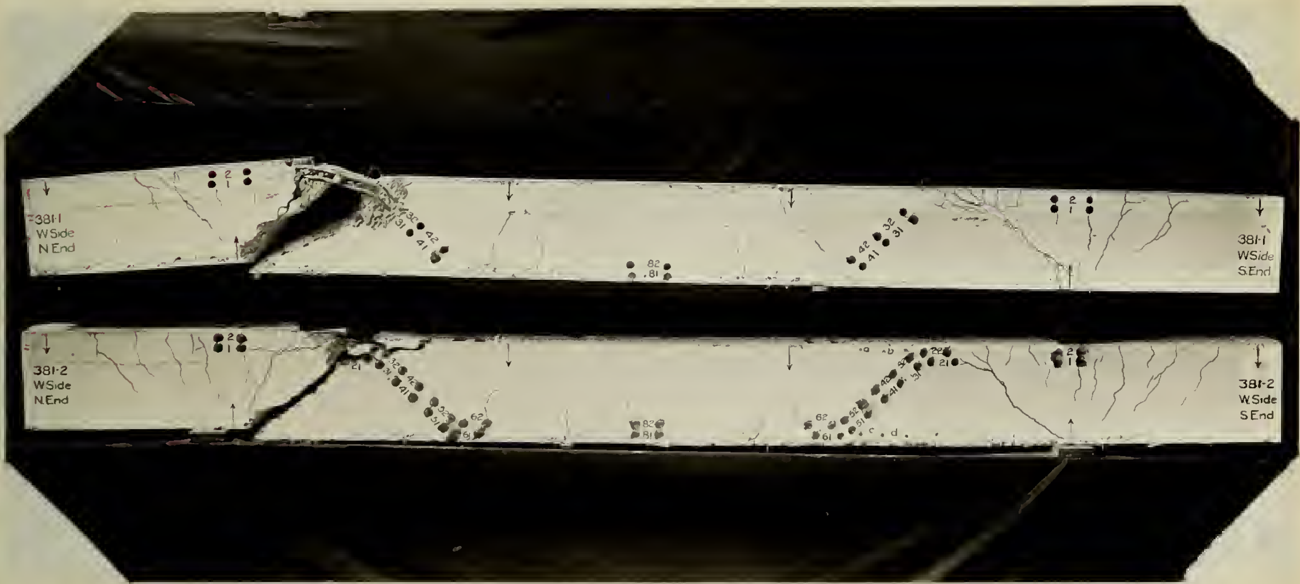

398-2
E.Side
N.End
Max. Load-173,100 Lb


399.1
41.6
41.6
62.5
62.5
62.5
83.3

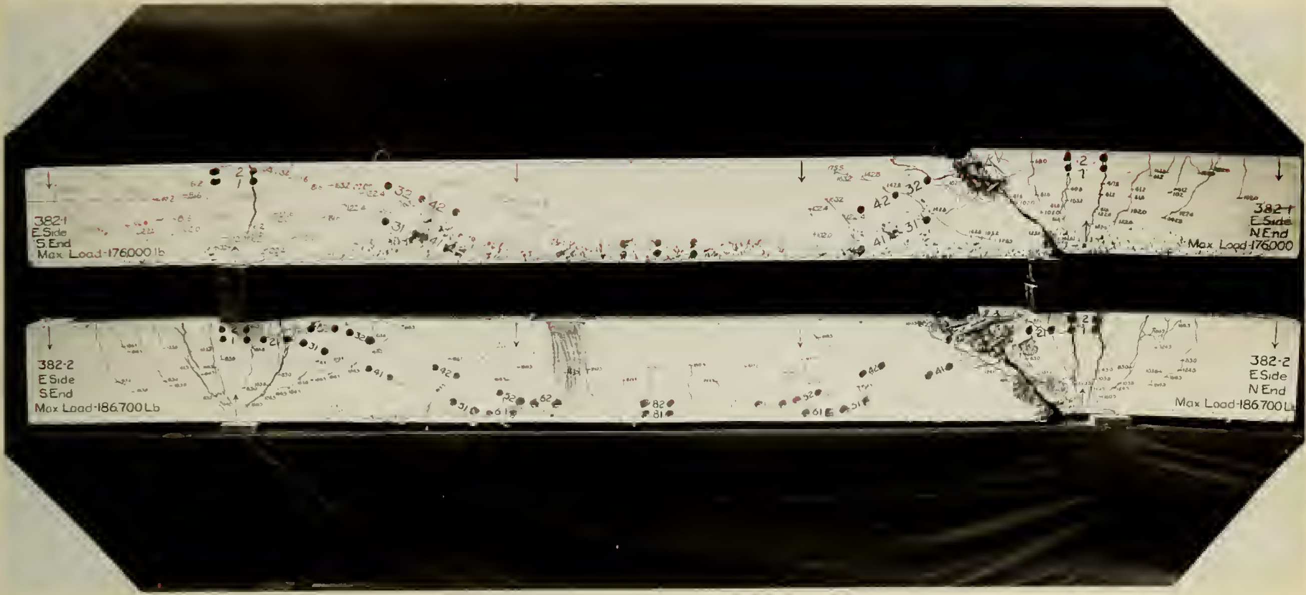

399.2

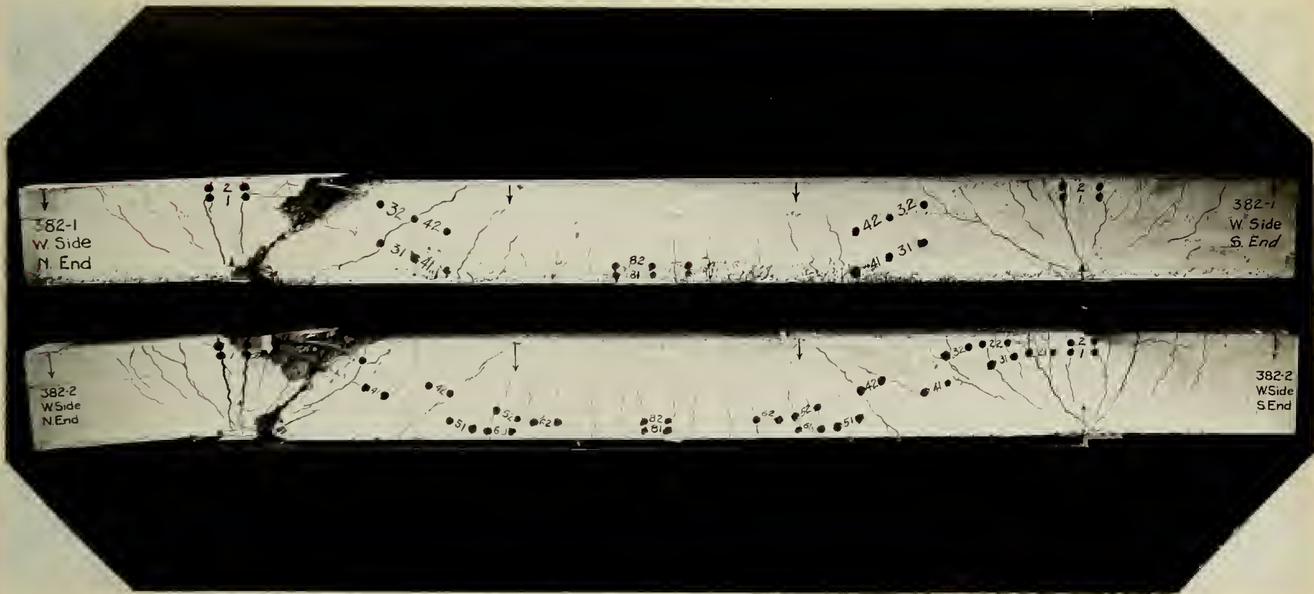


E Side
S End
381-1
Max Load, 165000 lb
E. Side
N End
381-1
Max Load, 165000
381-2
E Side
S End
Max Load-124,100 Lb
381-2
E Side
N End
Max Load-124,100 Lb

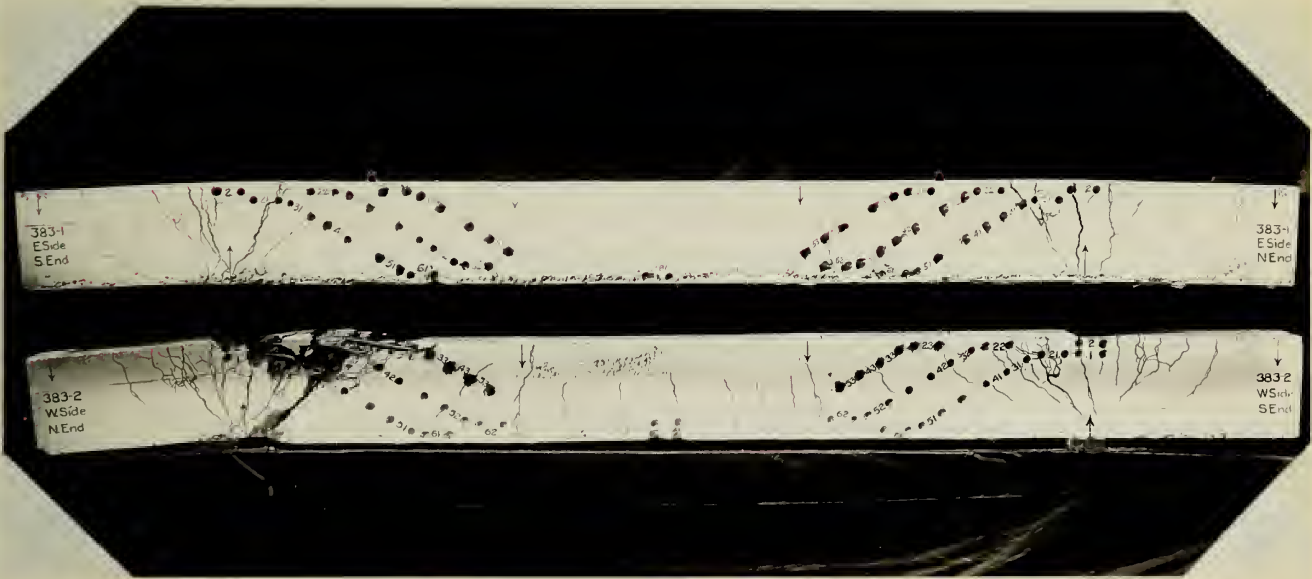


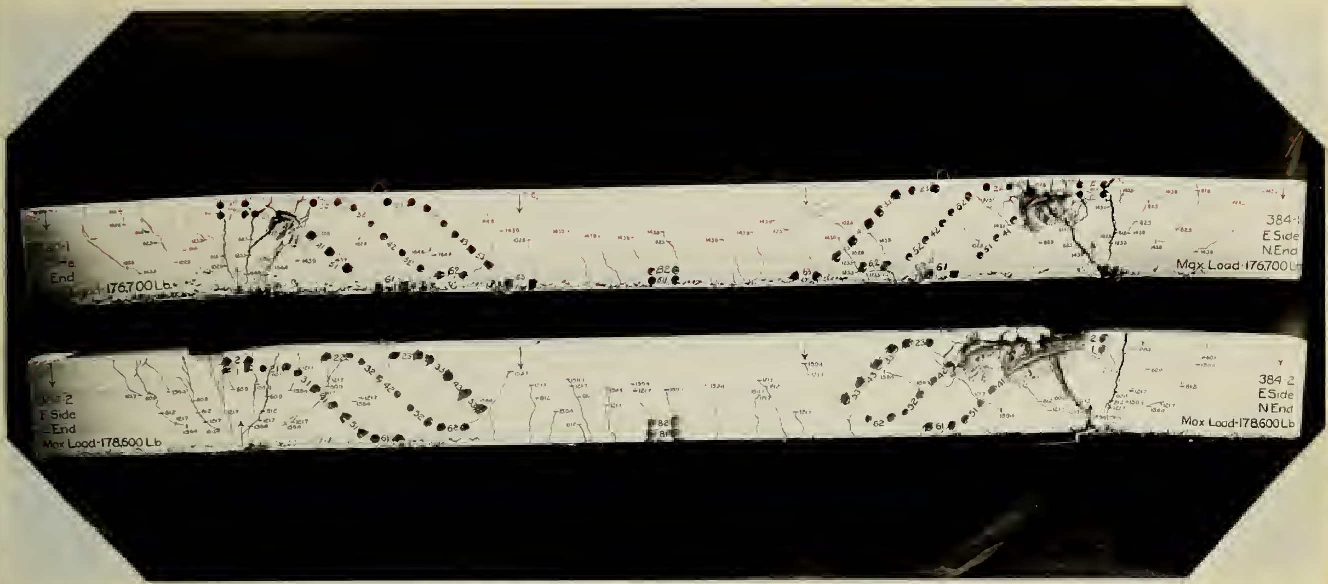
381-1
W Side
N End
381-1
W Side
S End
381-2
W Side
N End
381-2
W Side
S End

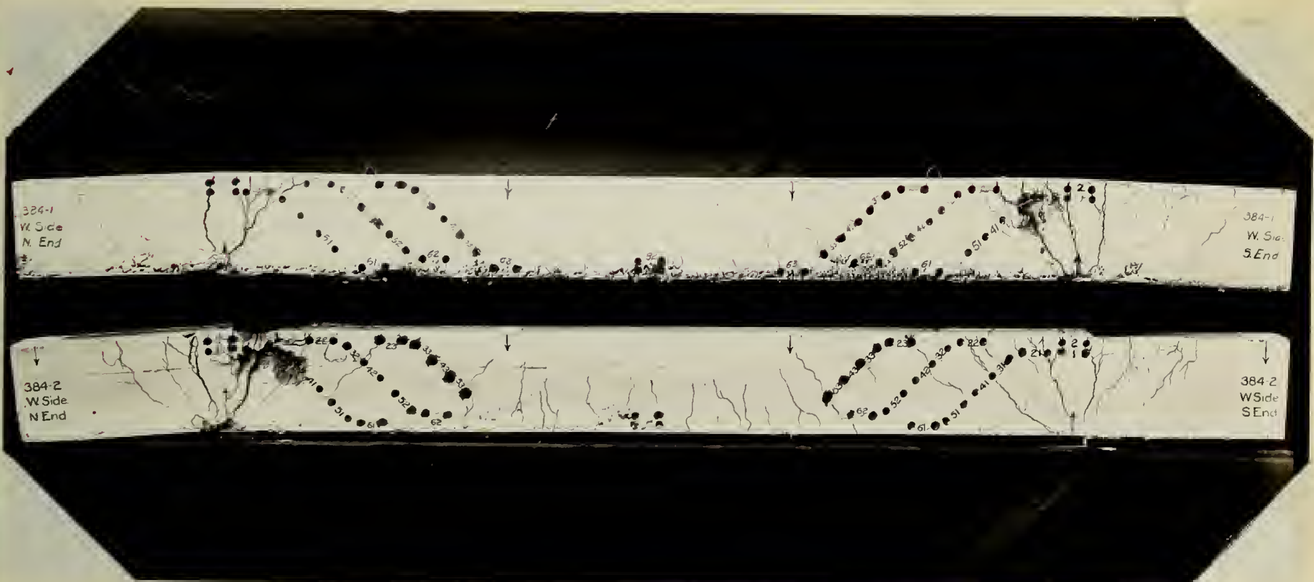

382-1
E. Side
S. End
Max. Load-176,000 lb
382-1
E. Side
N. End
Max. Load-176,000
382-2
E. Side
S. End
Max. Load-186,700 Lb
382-2
E. Side
N. End
Max. Load-186,700 Lb

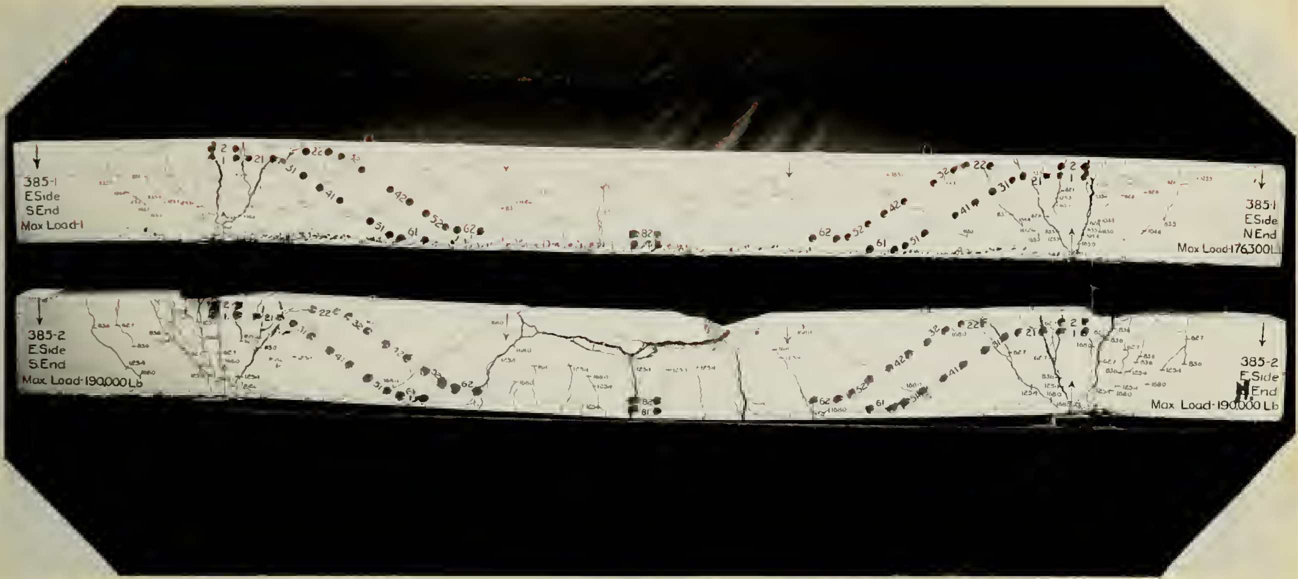

382-1
W. Side
N. End
382-1
W. Side
S. End
382-2
W. Side
N. End
382-2
W. Side
S. End

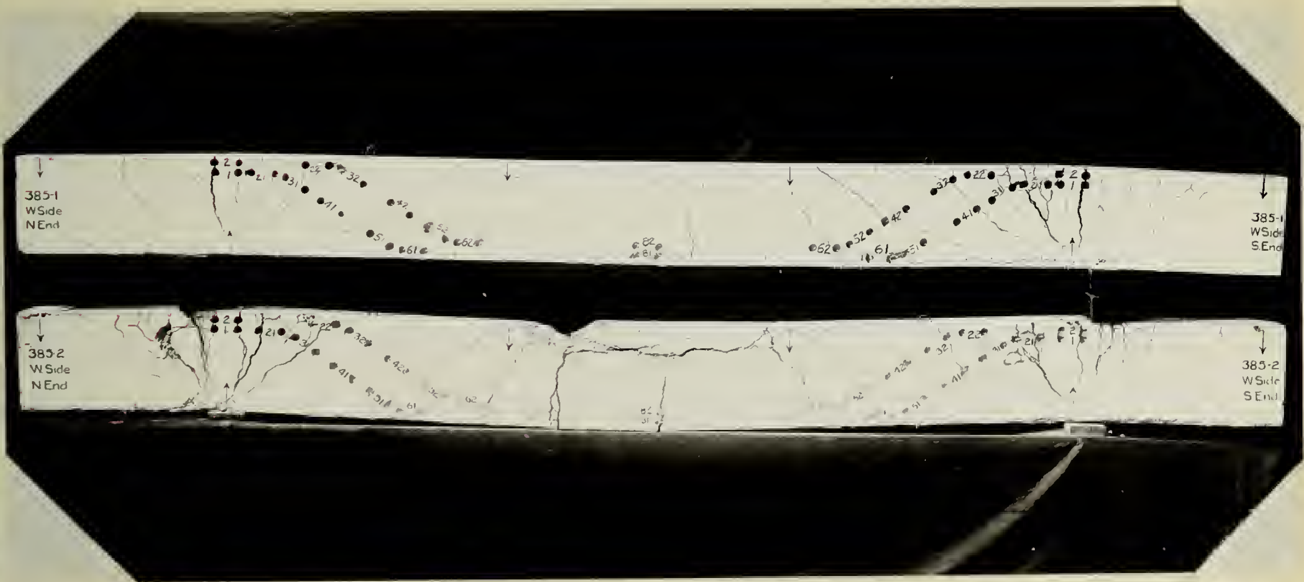

383-1
W Side
N End
Max Load 183200
Max Load 181,500 Lb
383-2
E Side
S End
Max Load 181,500 Lb

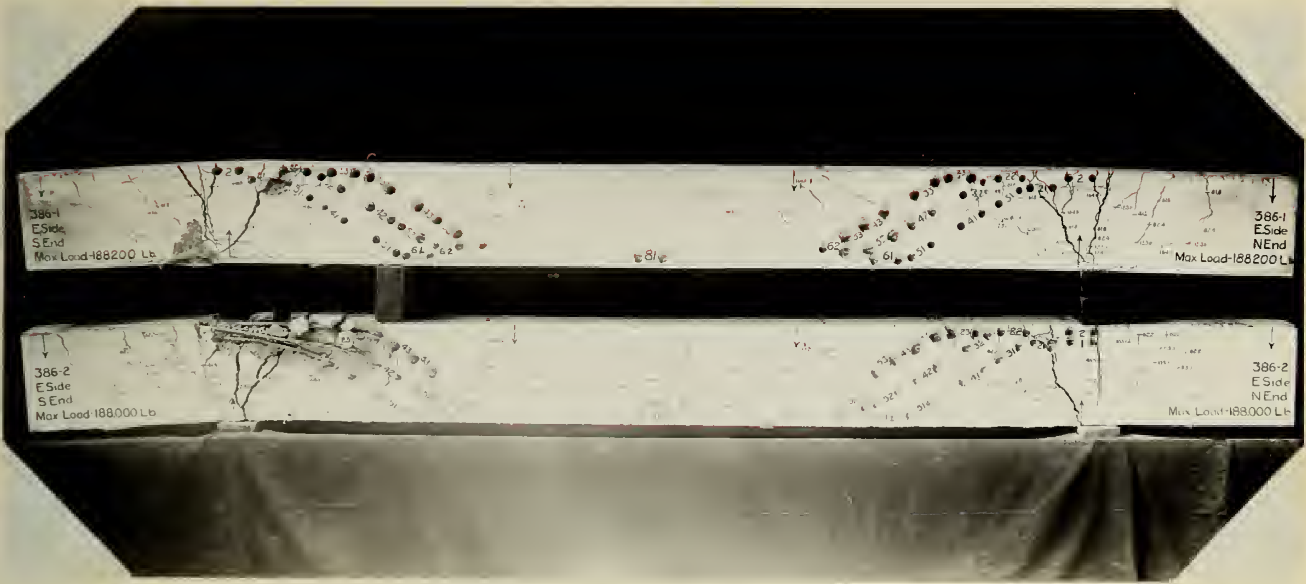

383-1
E Side
S End
383-1
E Side
N End
383-2
W Side
N End

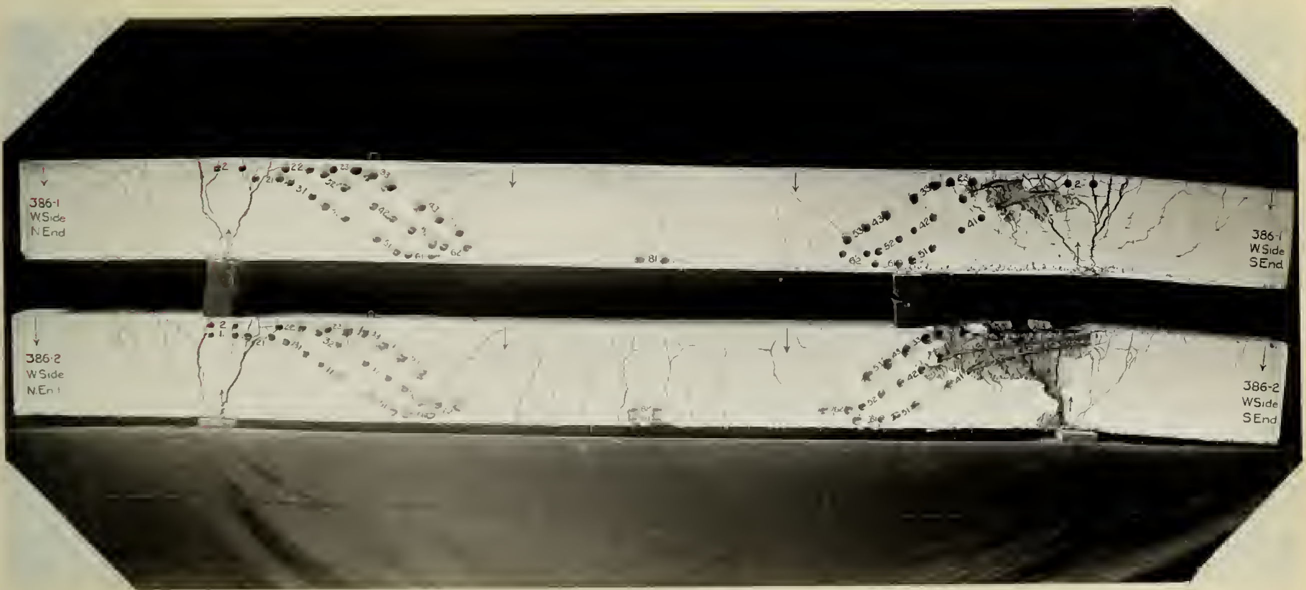

384-1
E Side
N End
Max Load-176,700 Lb
Max Load-178,600 Lb
384-2
E Side
N End
Max Load-178,600 Lb

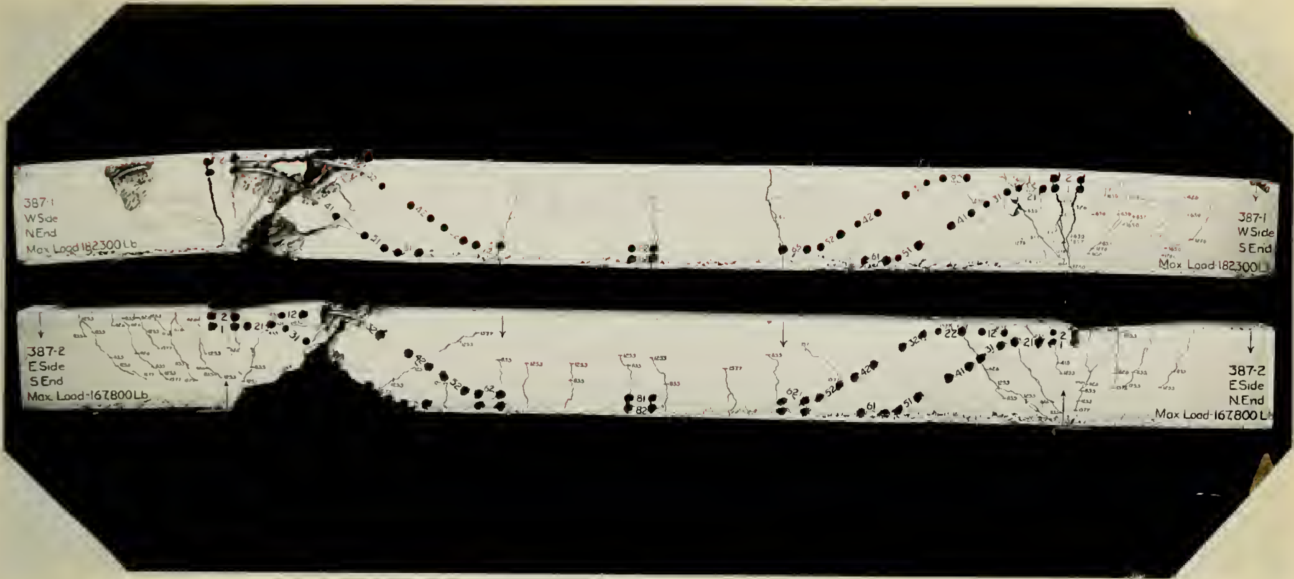

384-1
W. Side
N. End
384-1
W. Side
S. End
384-2
W Side
N End
384-2
W Side
S End

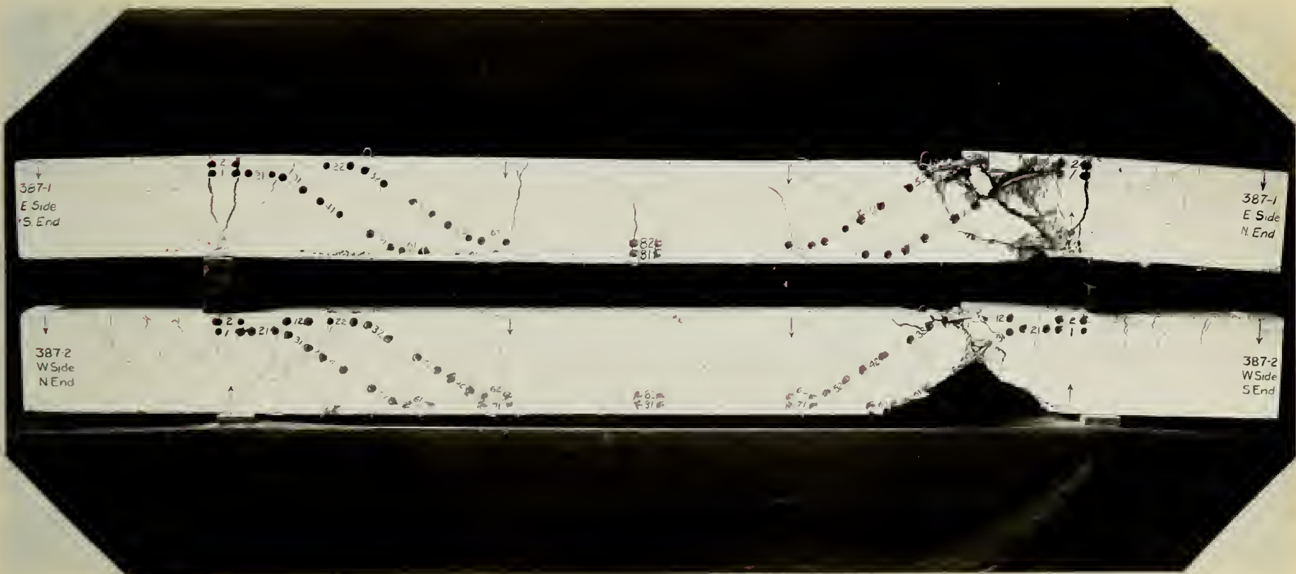

385-1
E Side
S End
Max Load-1
385-1
E Side
N End
Max Load-176300 Lb
385-2
E Side
S End
Max Load-190,000 Lb
385-2
E Side
N End
Max Load-190,000 Lb

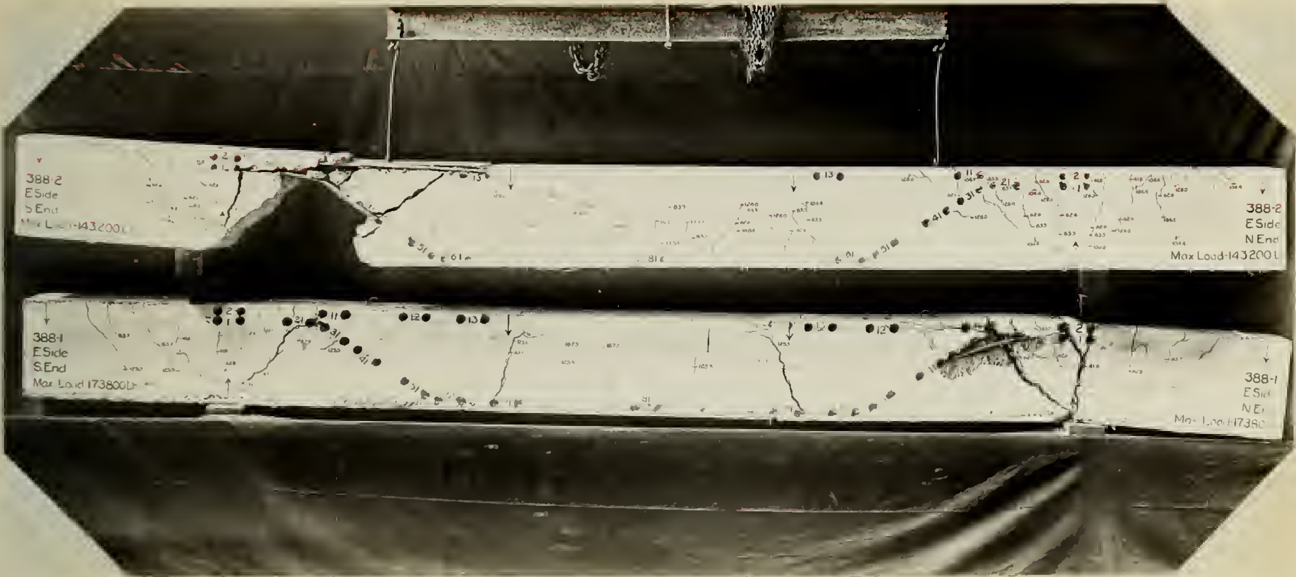

385-1
W Side
N End
385-1
W Side
S End
385-2
W Side
N End
385-2
W Side
S End

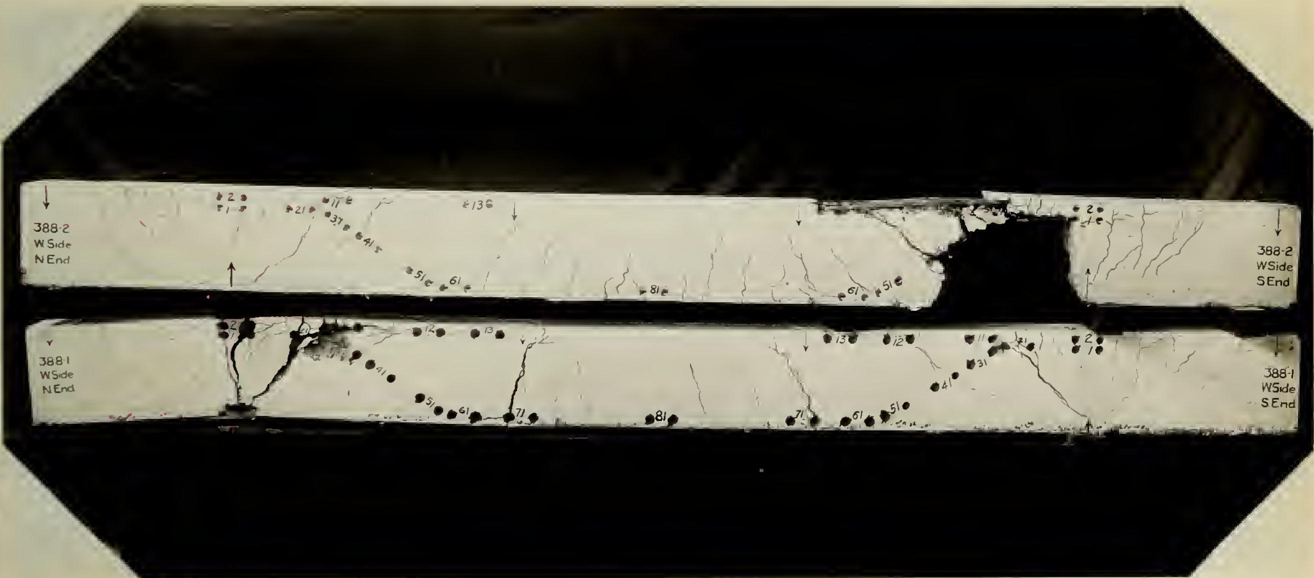

386-1
E Side
S End
Max Load-188200 Lb
386-1
E Side
N End
Max Load-188200 Lb
386-2
E Side
S End
Max Load-188,000 Lb
386-2
E Side
N End
Max Load-188,000 Lb


386-1
W Side
N End
386-1
W Side
S End
386-2
W Side
N End
386-2
W Side
S End


387-1
W Side
N End
Max Load 182300 Lb
387-1
W Side
S End
Max Load 182300 Lb
387-2
E Side
S End
Max Load 167800 Lb
387-2
E Side
N End
Max Load 167800 Lb

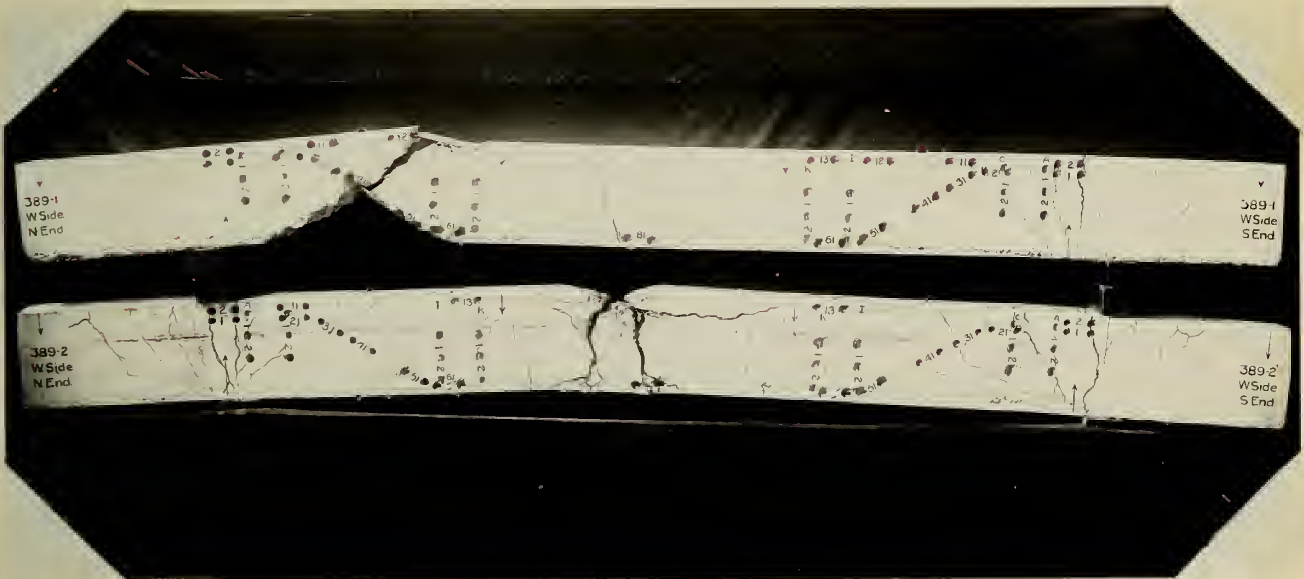

387-1
E Side
S End
387-1
E Side
N End
387-2
W Side
N End
387-2
W Side
S End

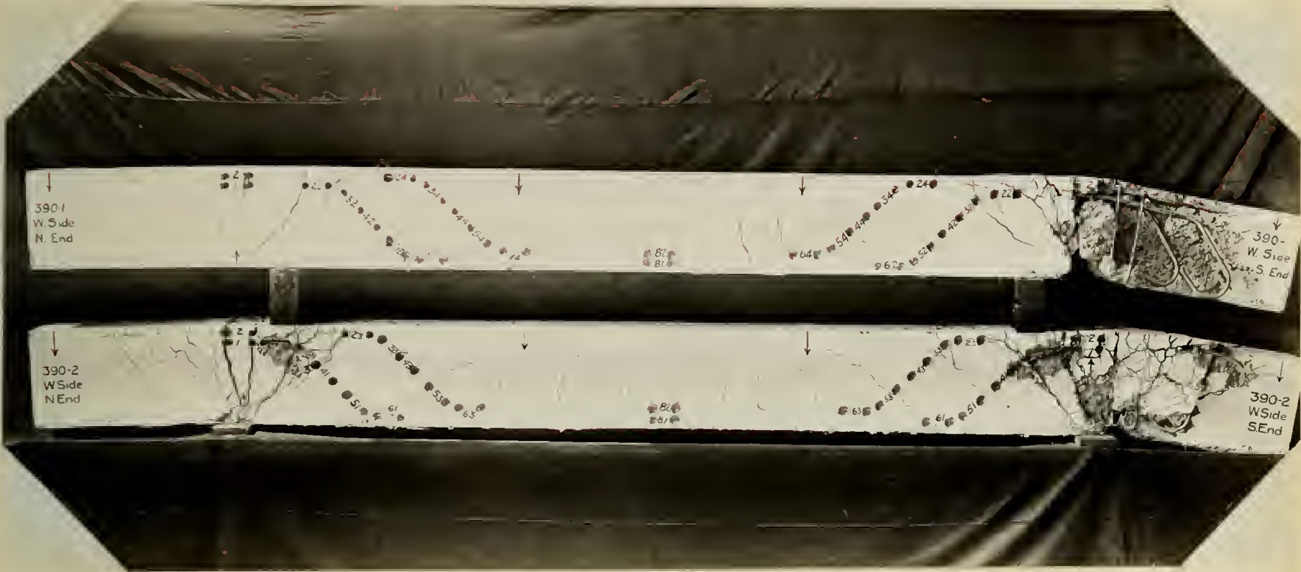

388-2
E Side
S End
388-2
E Side
N End
Max Load-143200 L
388-1
E Side
S End
Max Load 173800 Lb
388-1

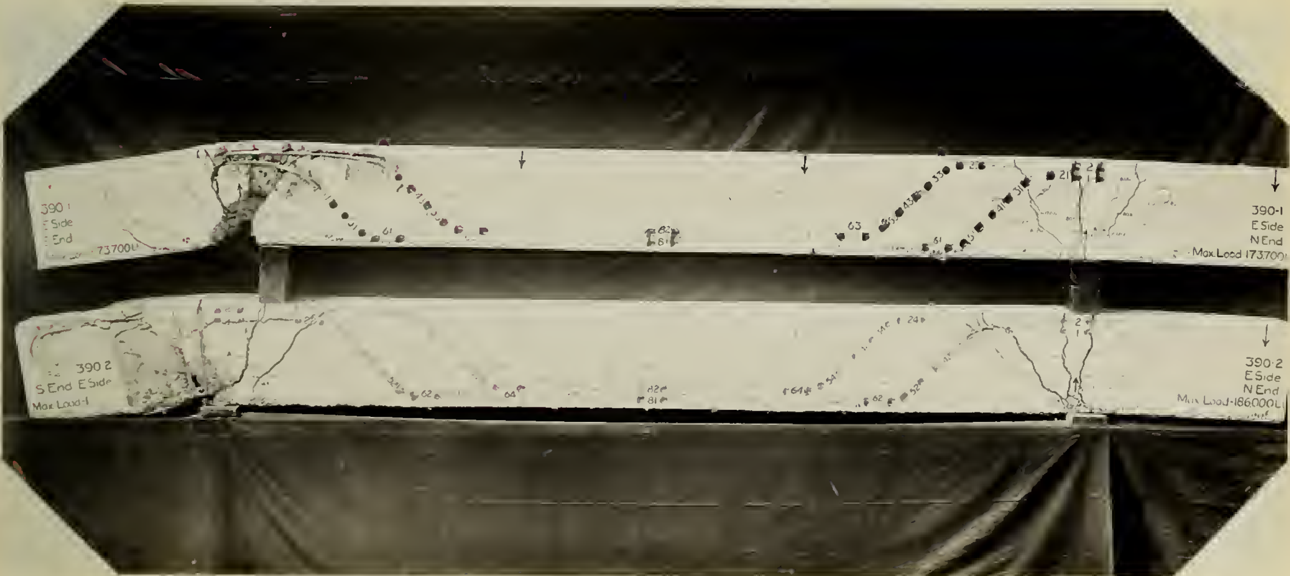

388-2
W Side
N End
388-2
W Side
S End
388-1
W Side
N End
388-1
W Side
S End

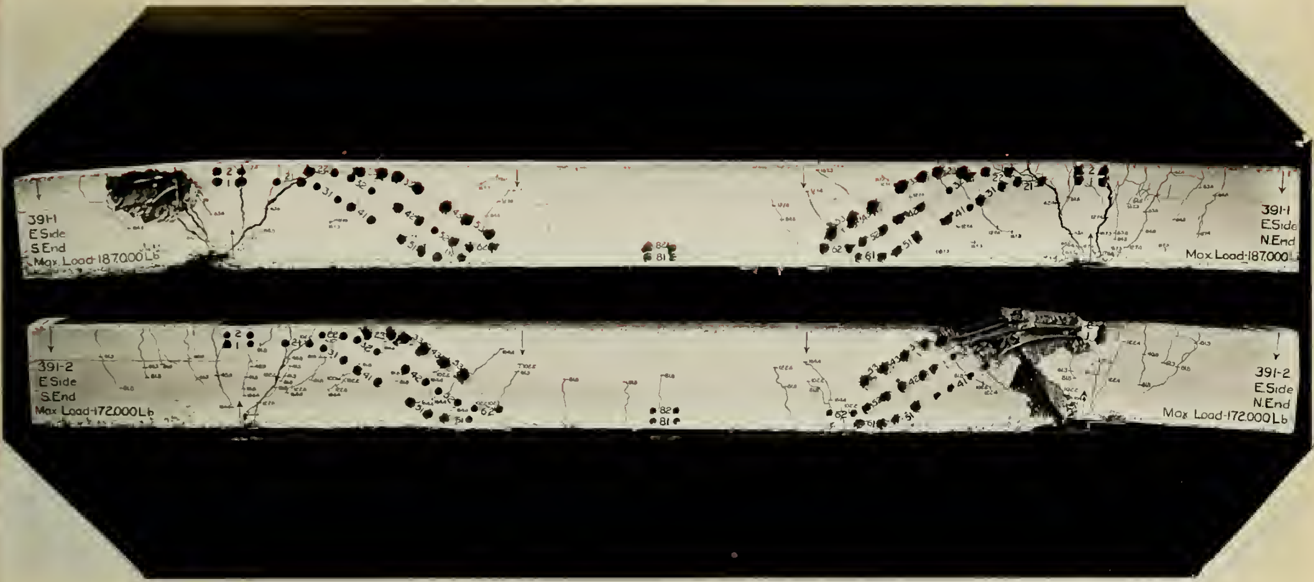
174

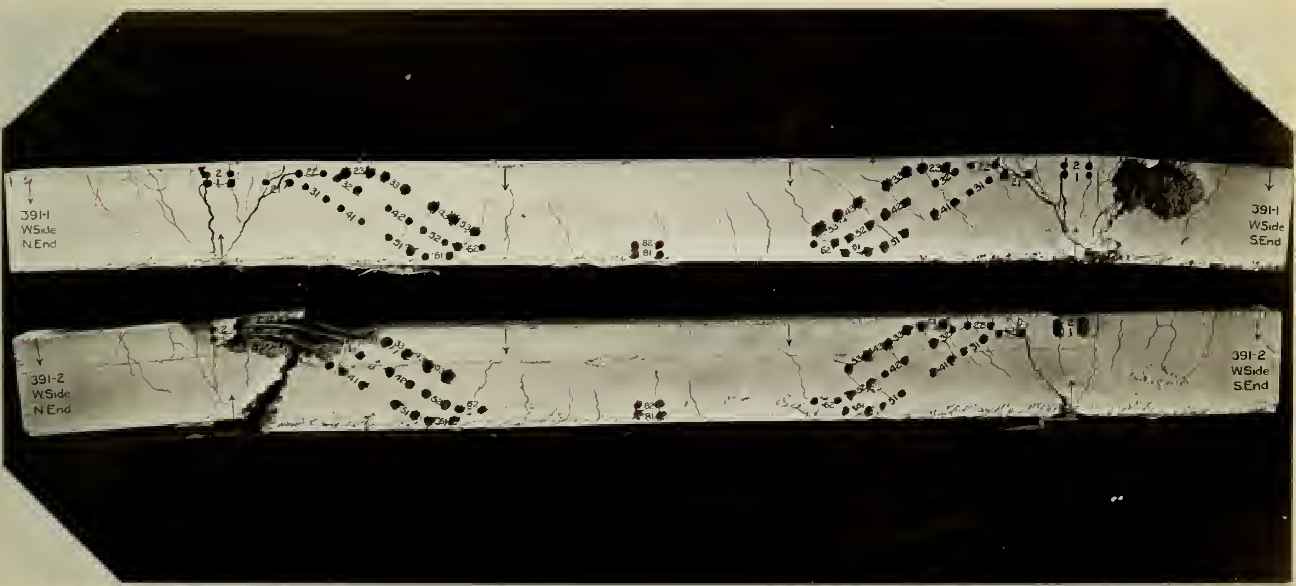

389-1
E Side
N End
Max Load 146,000
389-2
E Side
S End
389-2
E Side
N End
Max Load-169,000

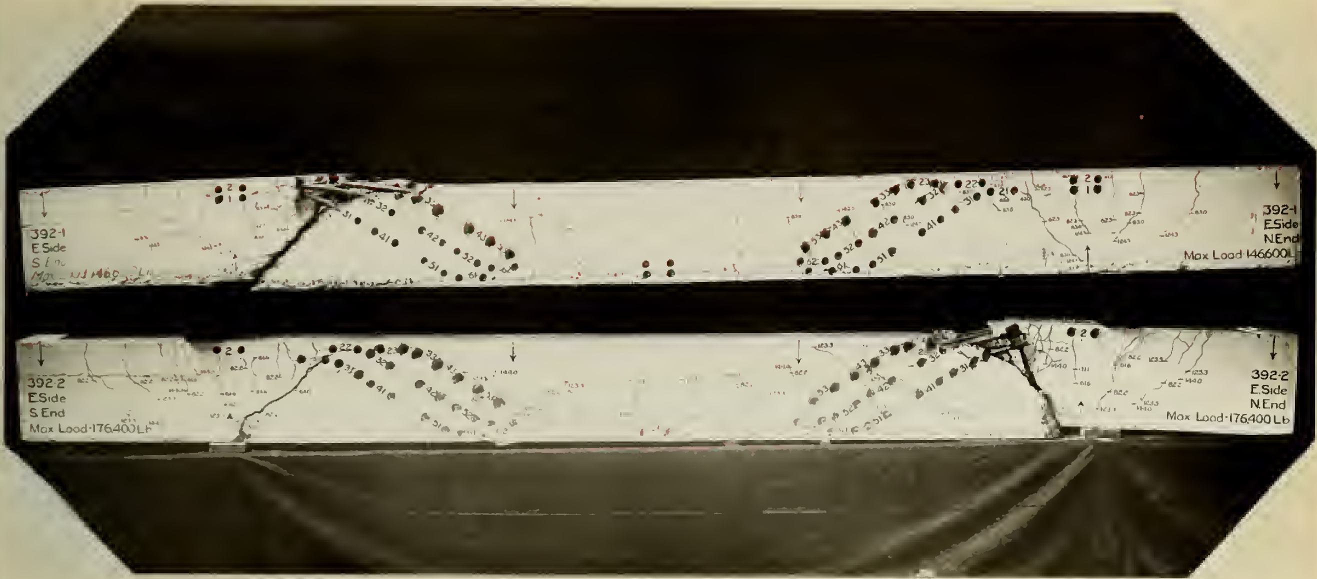

389-1
W Side
N End
389-1
W Side
S End
389-2
W Side
N End
389-2
W Side
S End

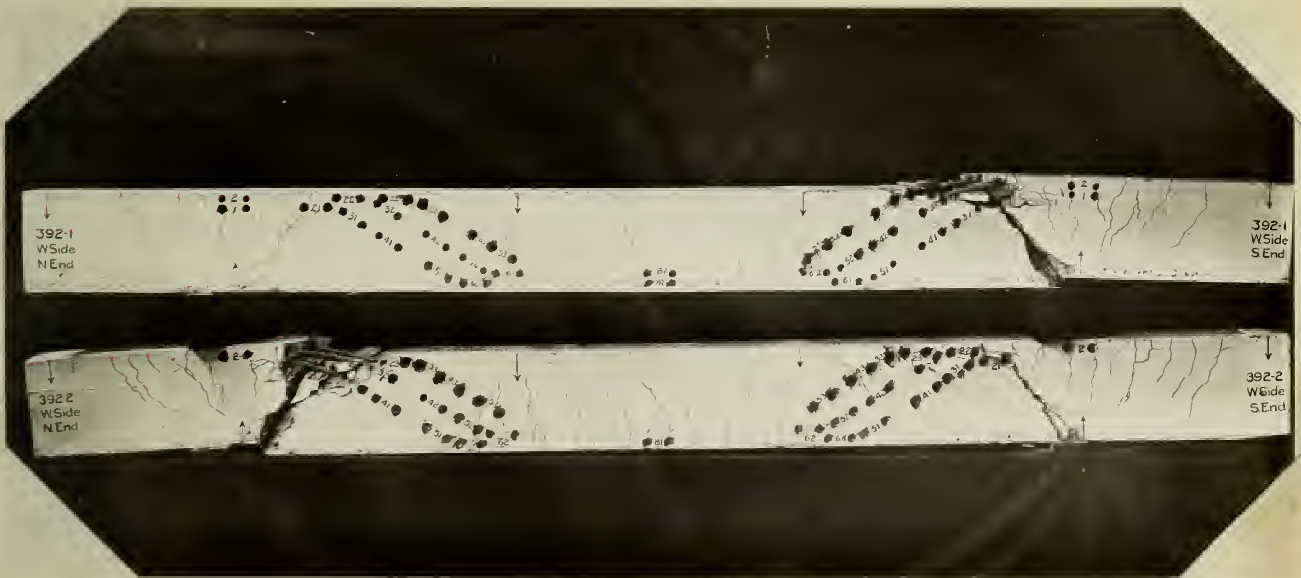

390-1
W. Side
N. End
390-
W. Side
S. End
390-2
W Side
N End
390-2
W Side
S End

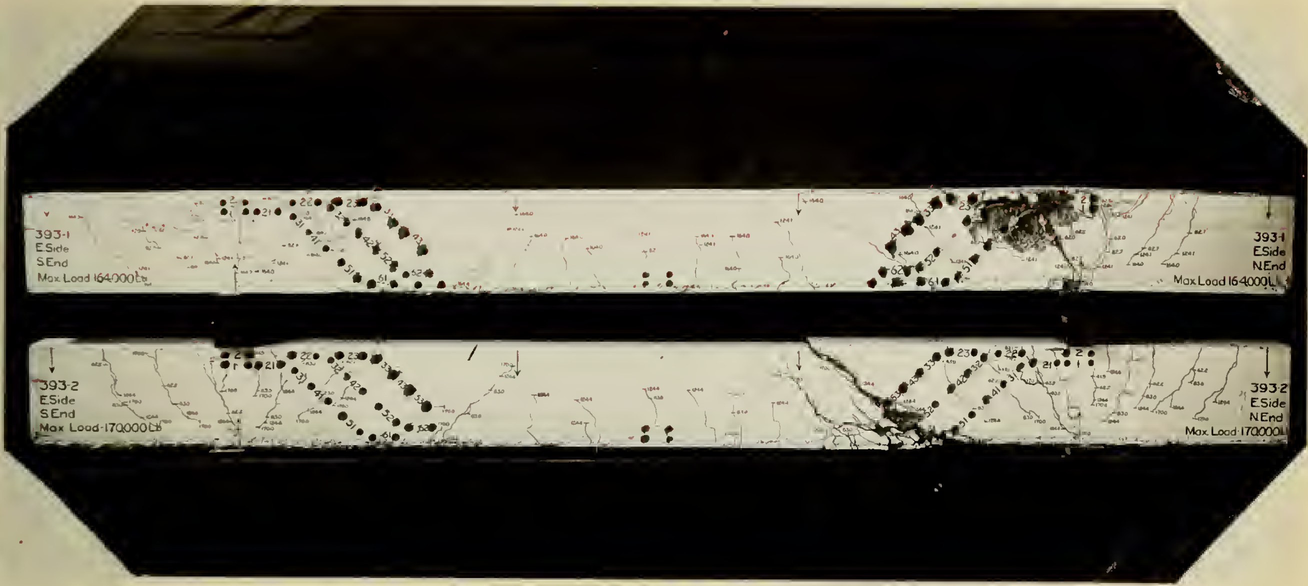

390-1
E Side
N End
Max. Load 173700
390-2
E Side
N End
Max Load 186000 L
390 2
S End E Side

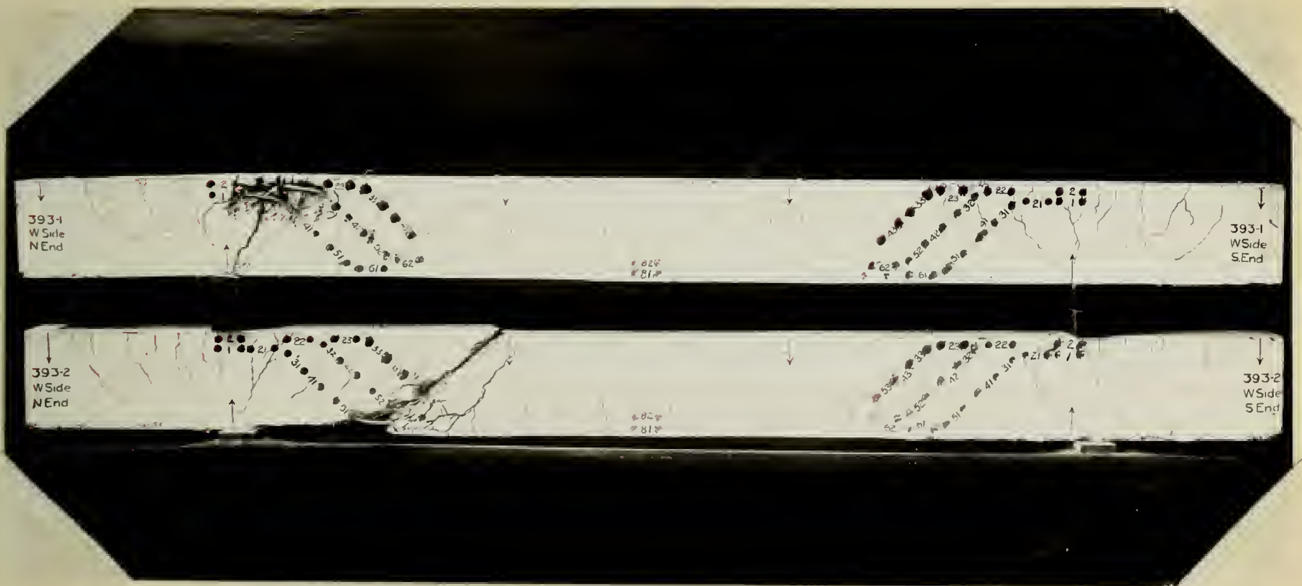

391-1
E Side
S End
Max Load-187,000 Lb
391-1
E Side
N End
Max Load-187,000
391-2
E Side
S End
Max Load-172,000 Lb
391-2
E Side
N End
Max Load-172,000 Lb

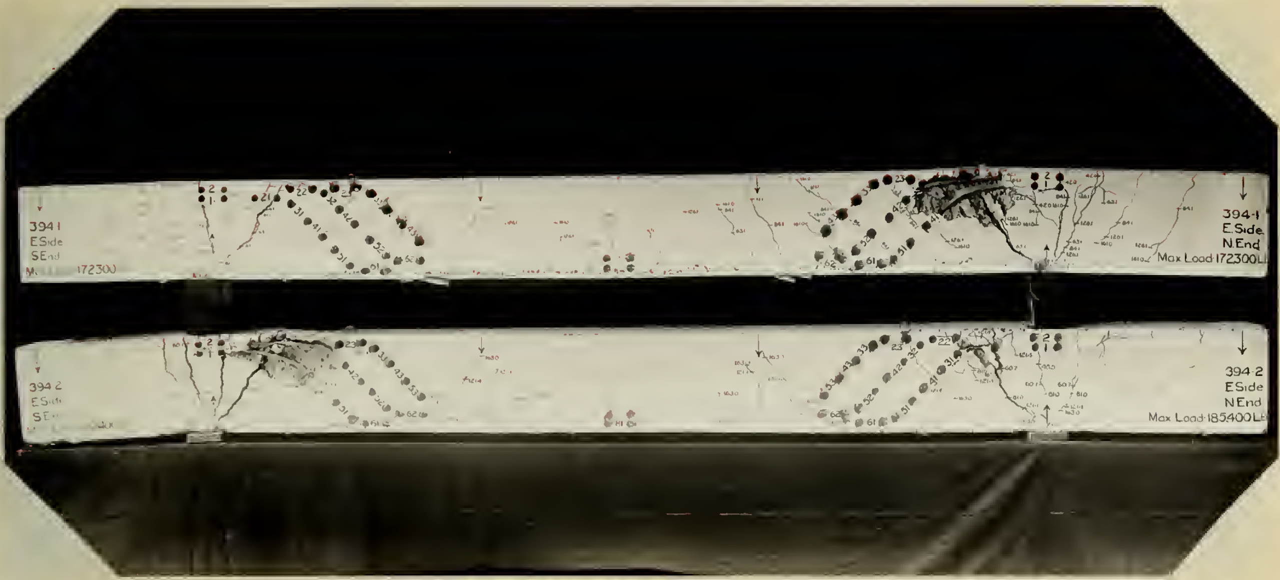

391-1
W Side
N End
391-1
W Side
S End
391-2
W Side
N End
391-2
W Side
S End

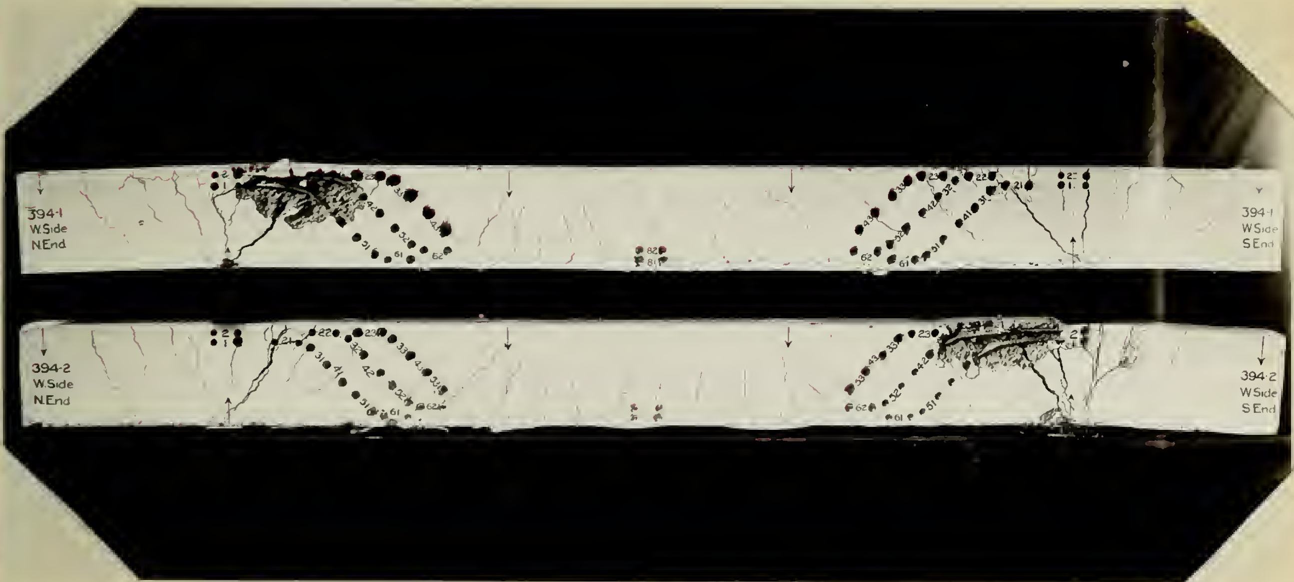

392-1
E Side
392-1
E Side
N End
Max Load 146600 L
392-2
E Side
S End
Max Load 176400 Lb
392-2
E Side
N End
Max Load 176400 Lb

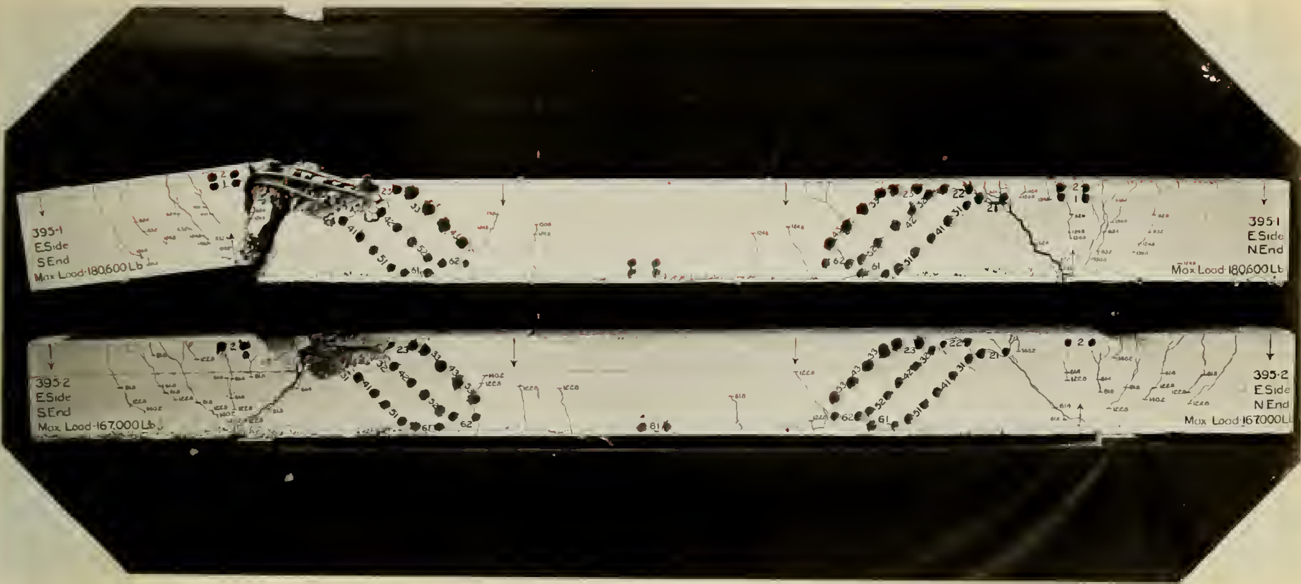

392-1
W Side
N End
392-1
W Side
S End
392-2
W Side
N End
392-2
W Side
S End

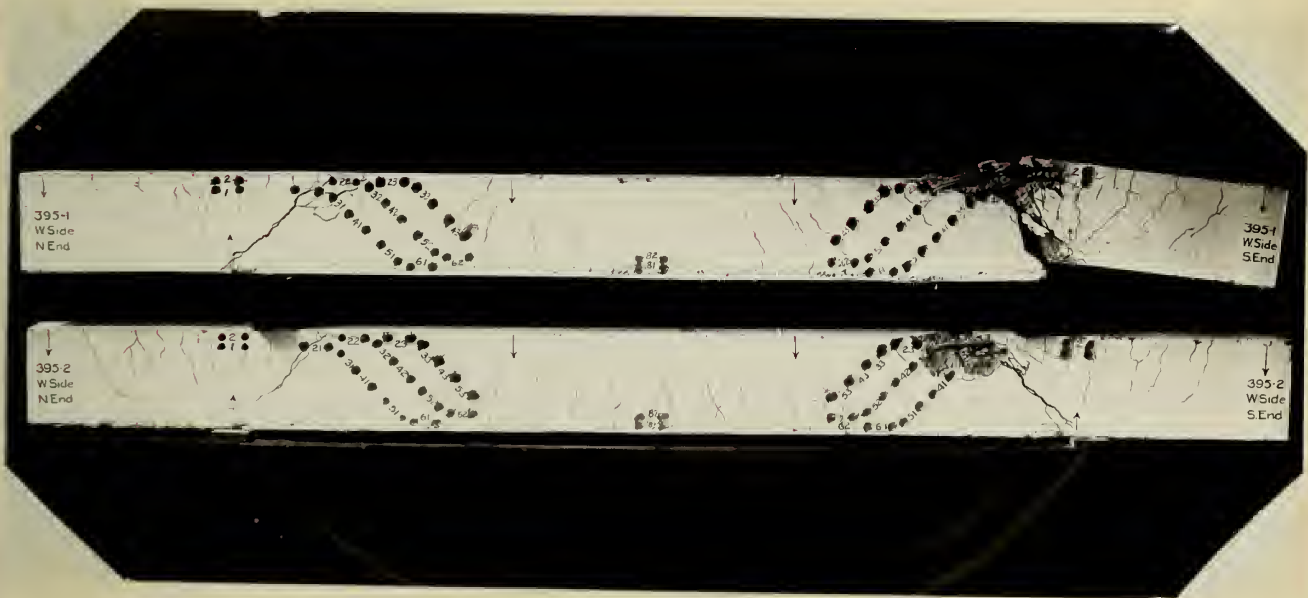

393-1
E Side
S End
Max Load 164000 Lb
393-1
E Side
N End
Max Load 164000 Lb
393-2
E Side
S End
Max Load 170000 Lb
393-2
E Side
N End
Max Load 170000 Lb

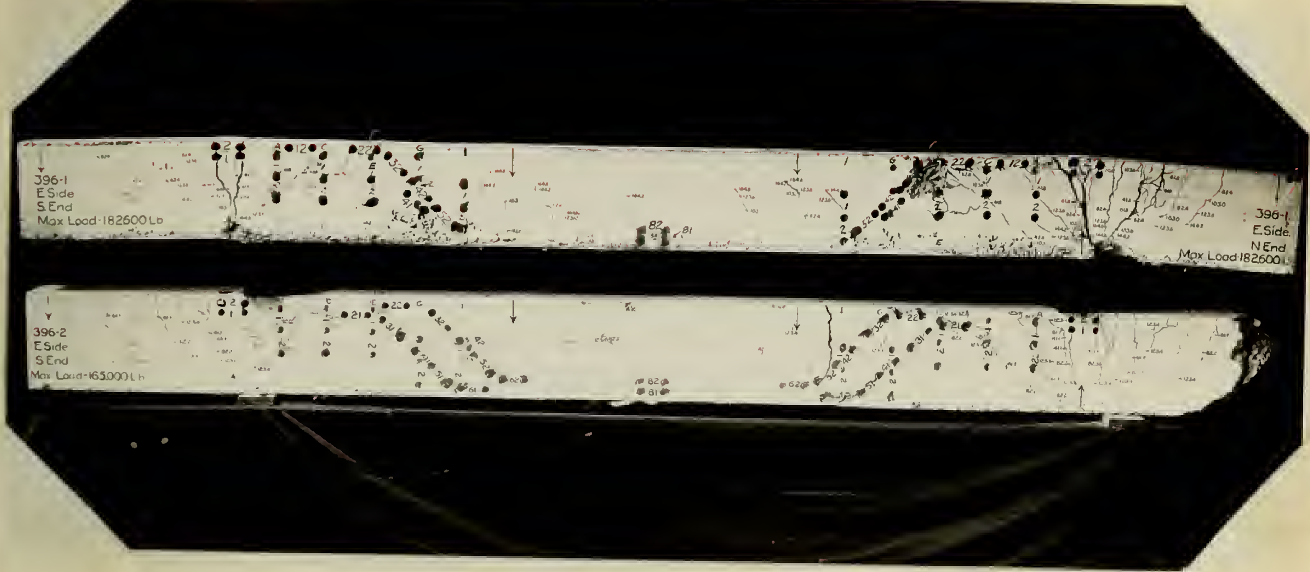

393-1
W Side
N End
393-1
W Side
S End
393-2
W Side
N End
393-2
W Side
S End

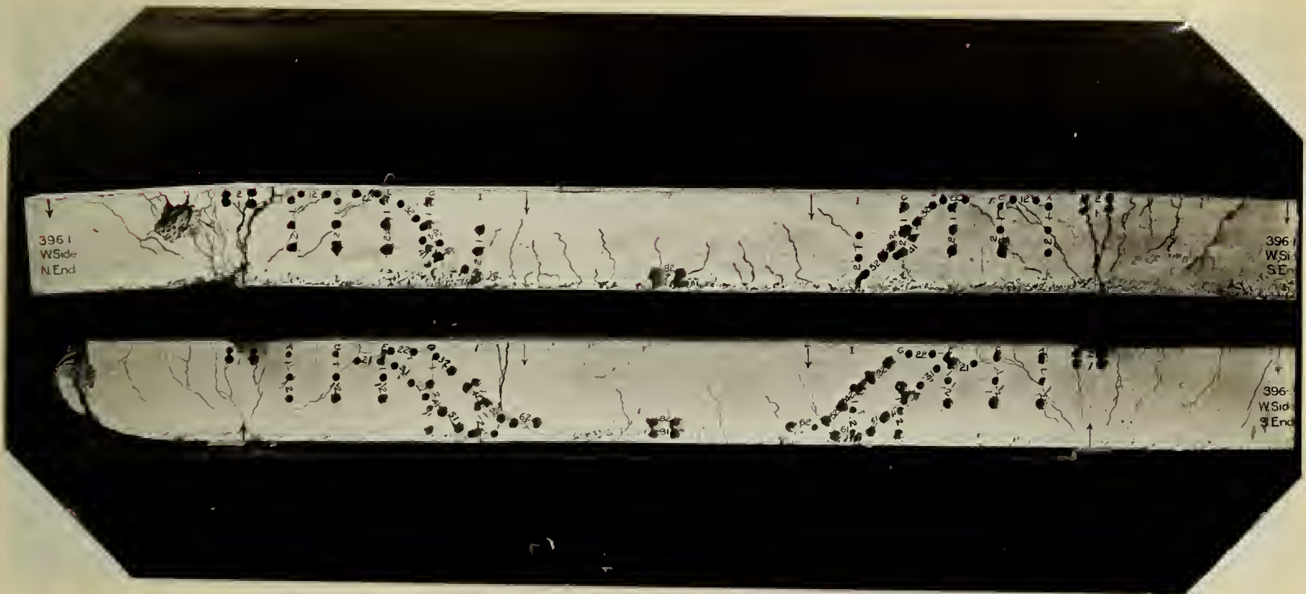

394-1
E.Side
S.End
394-1
E.Side
N.End
Max Load 172300 LB
394-2
E.Side
S.End
394-2
E.Side
N.End
Max Load 185400 LB


394-1
W.Side
N.End
394-1
W.Side
S.End
394-2
W.Side
N.End
394-2
W.Side
S.End

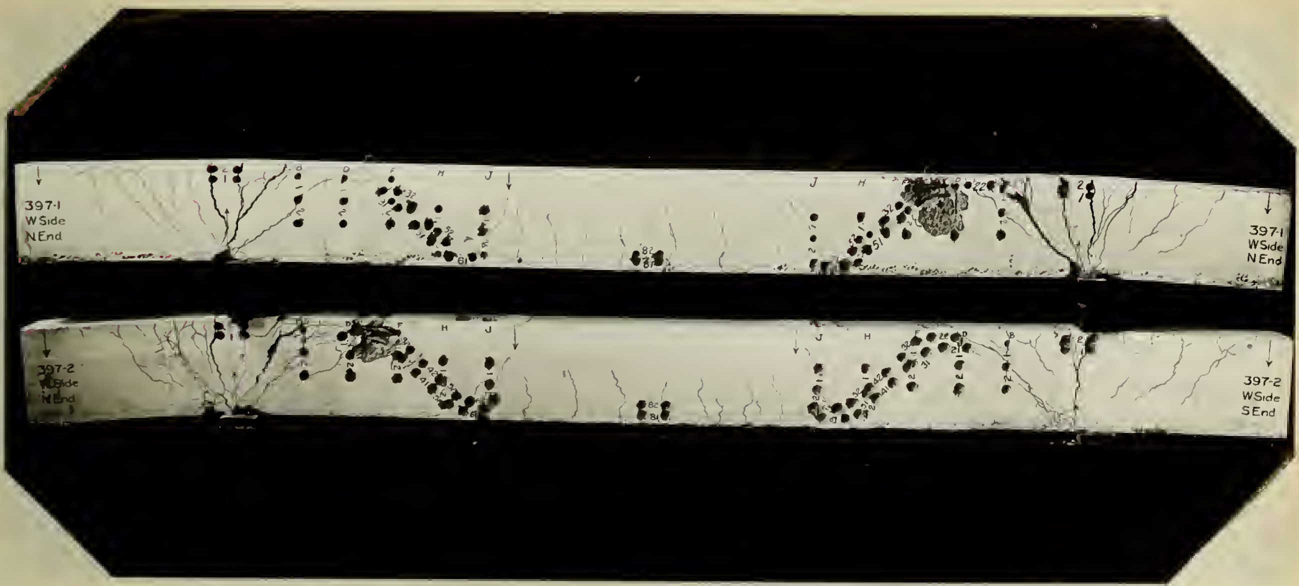

395-1
E Side
S End
Max Load 180,600 Lb
395-1
E Side
N End
Max Load 180,600 Lb
395-2
E Side
S End
Max Load 167,000 Lb
395-2
E Side
N End
Max Load 167,000 Lb


395-1
W Side
N End
395-1
W Side
S End
395-2
W Side
N End
395-2
W Side
S End


396-1
E Side
S End
Max Load 182600 Lb
396-1
E Side
N End
Max Load 182600
396-2
E Side
S End
Max Load 165000 Lb

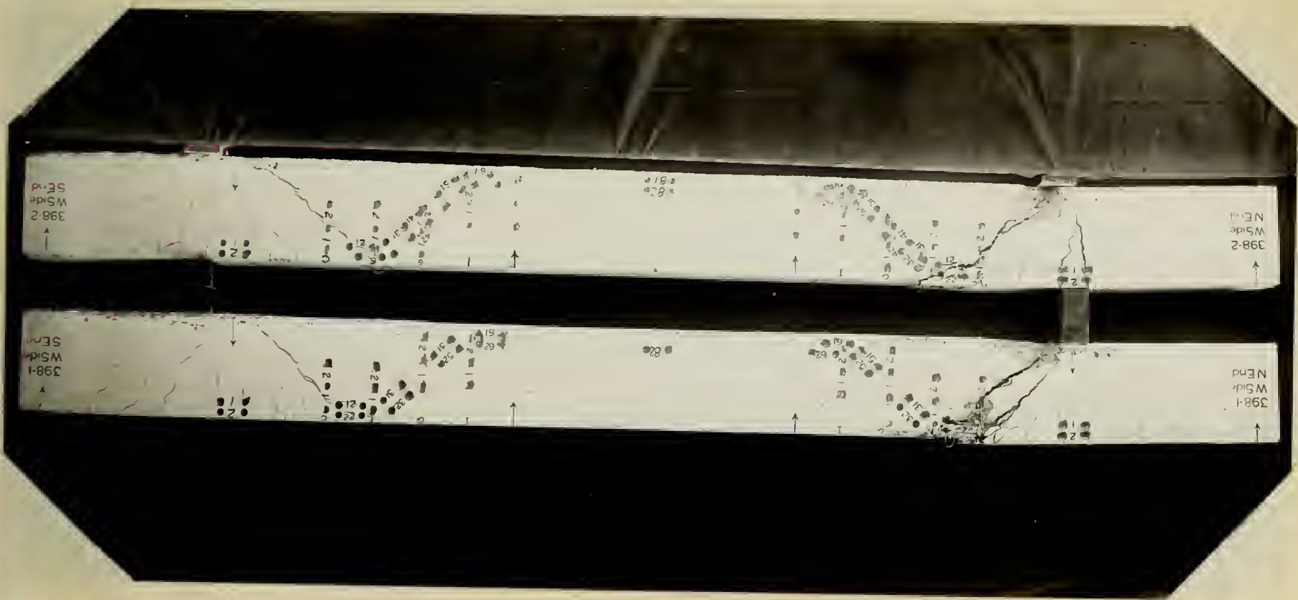

396-1
W Side
N End

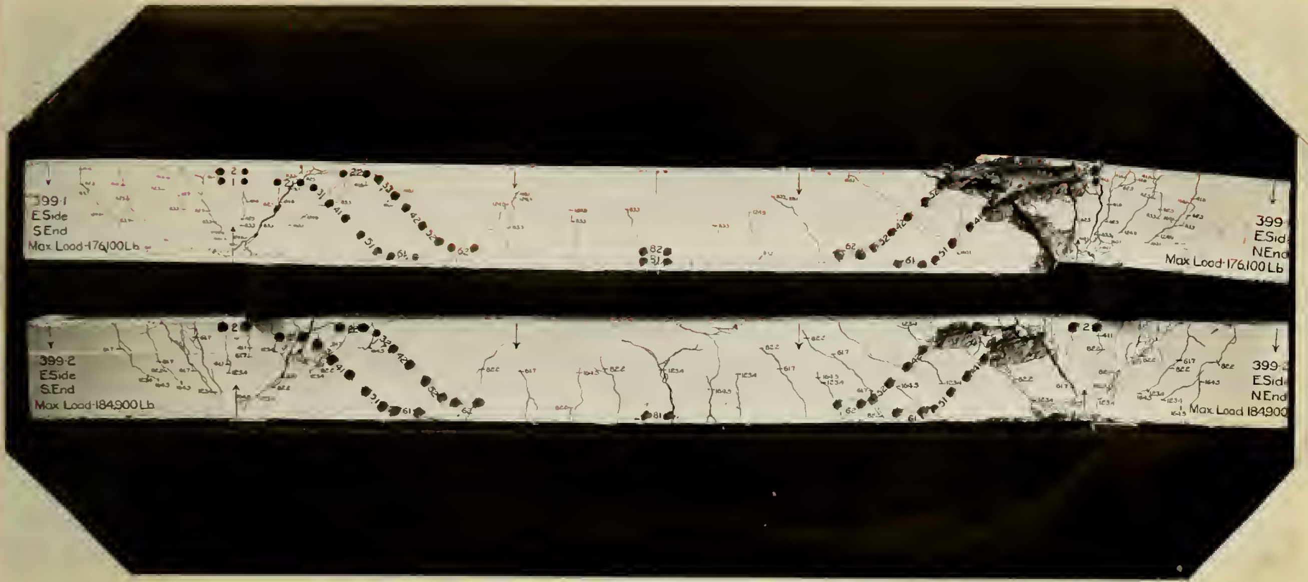

397-1
E Side
S End
Max Load-192,500 Lb
397-1
E Side
N End
Max Load-192,500
397-2
E Side
S End
Max Load-179,600
397-2
E Side
N End
Max Load-179,600 Lb


397-1
W Side
N End
397-1
W Side
N End
397-2
W Side
S End

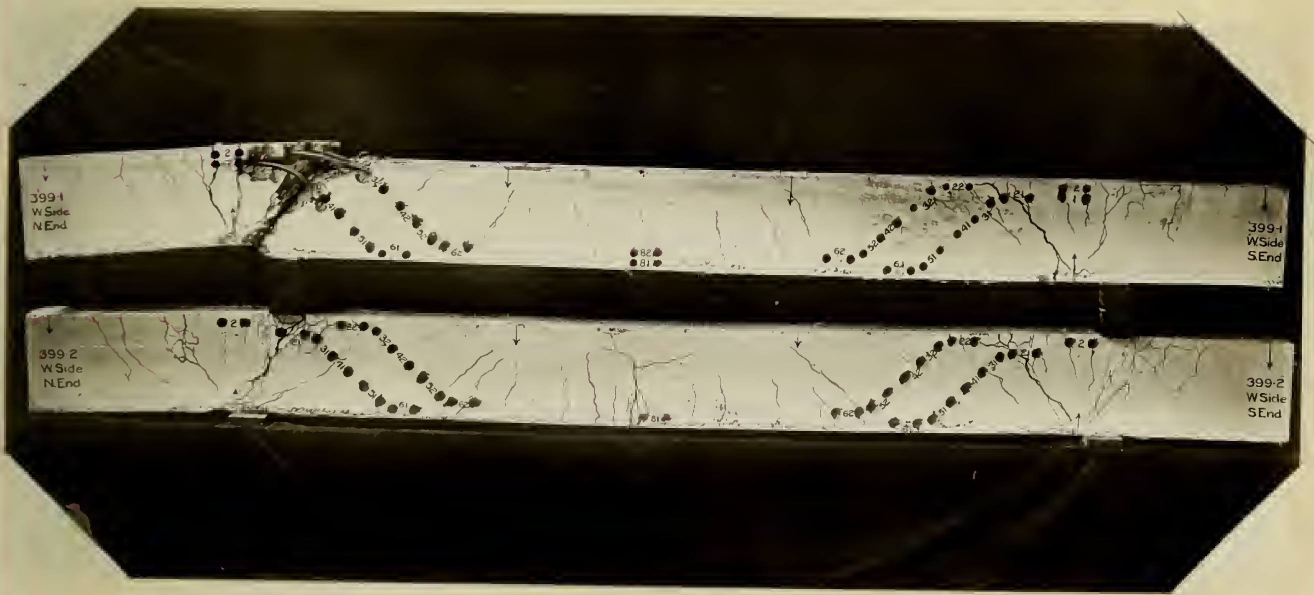
[illegible]


398-1
E Side
N End
Max Load-168000 Lb
398-2
E Side
N End
Max Load-173100 Lb



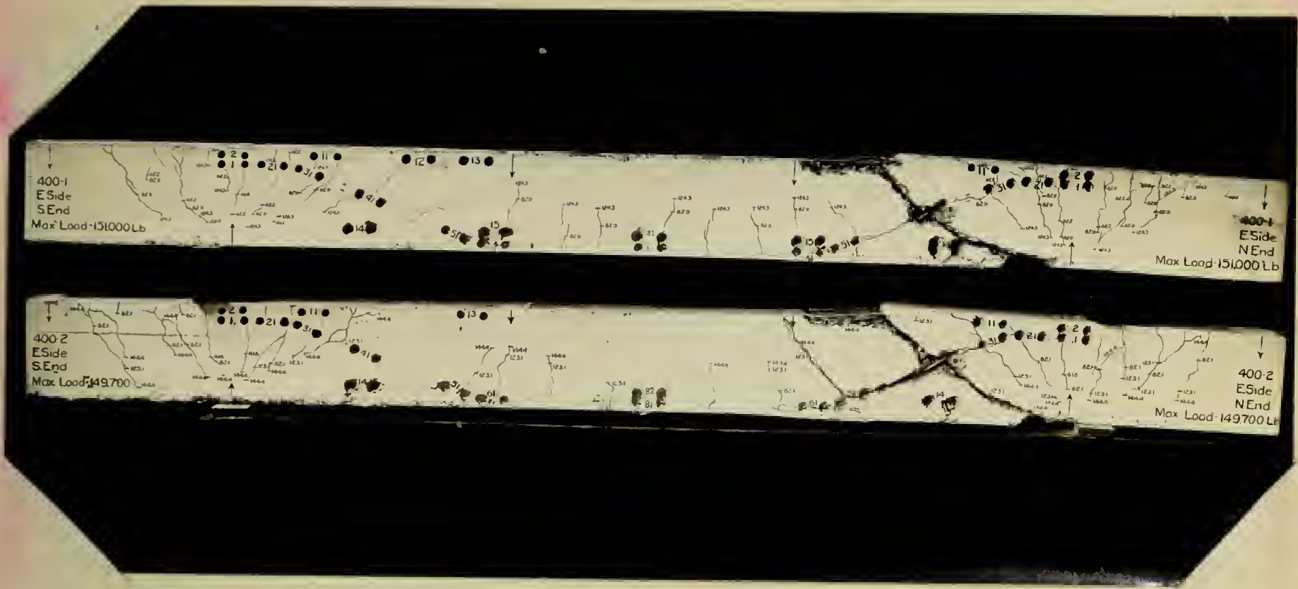


399-1
E.Side
S.End
Max Load-176,100 Lb
399-1
E.Sid
N.End
Max Load-176,100 Lb
399-2
E.Side
S.End
Max Load-184,900 Lb
399-2
E.Side
N.End
Max Load 184,900



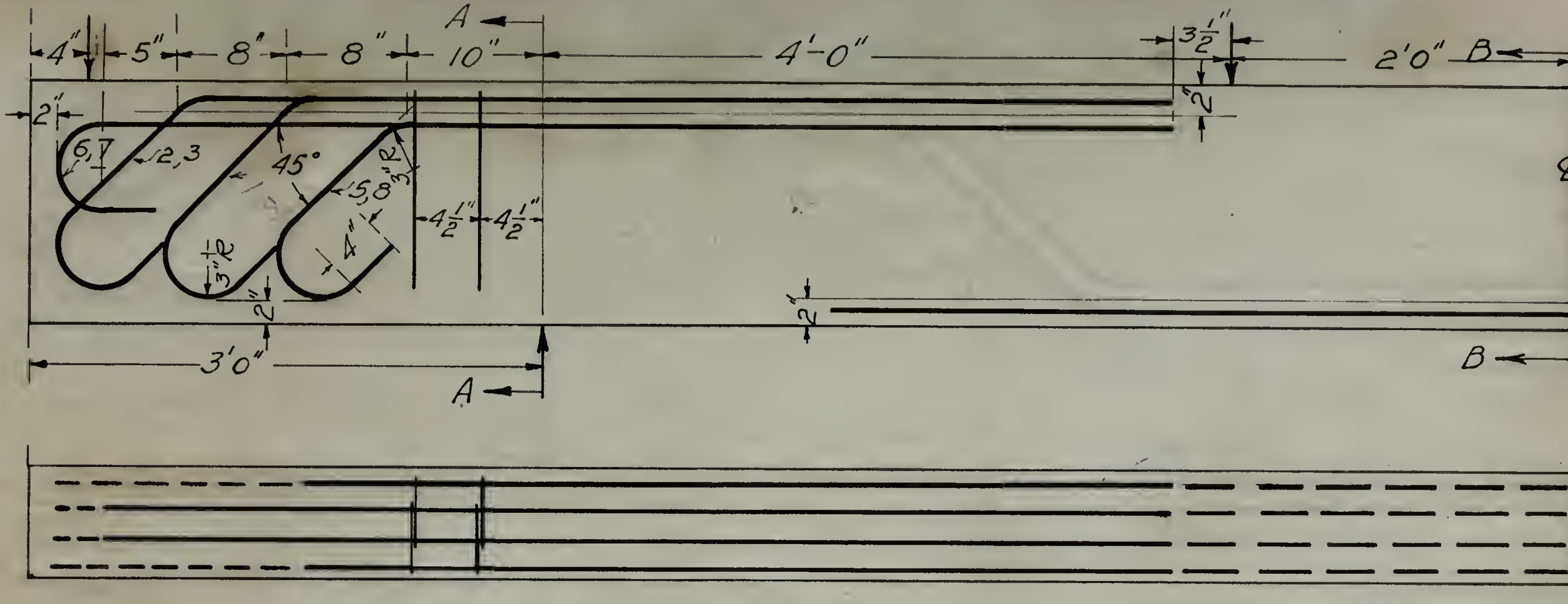
399-1
W.Side
N.End
399-1
W.Side
S.End
399-2
W.Side
N.End
399-2
W.Side
S.End

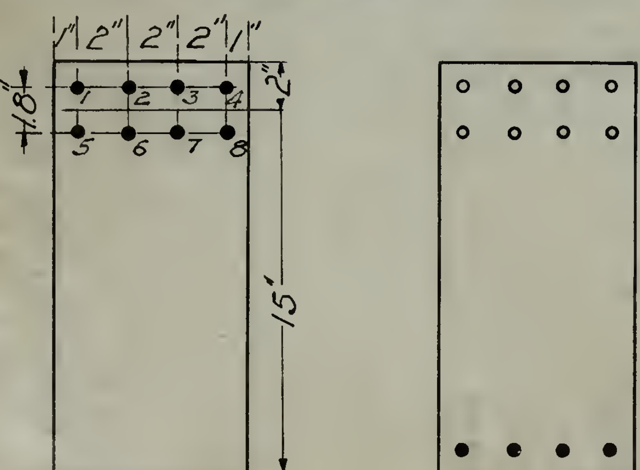
[illegible]


400-1
E Side
S End
Max Load 151,000 Lb
400-1
E Side
N End
Max Load 151,000 Lb
400-2
E Side
S End
Max Load 149,700
400-2
E Side
N End
Max Load 149,700 Lb


400-1
W Side
400-1
W Side
S End

Beam 380





AA

Sec. AA same for all beams

BB

Note:

For all beams.

Radius of bends = 3."

Dimensions of hooks, spacing of bent down bars and stirrups outside supports as shown above.

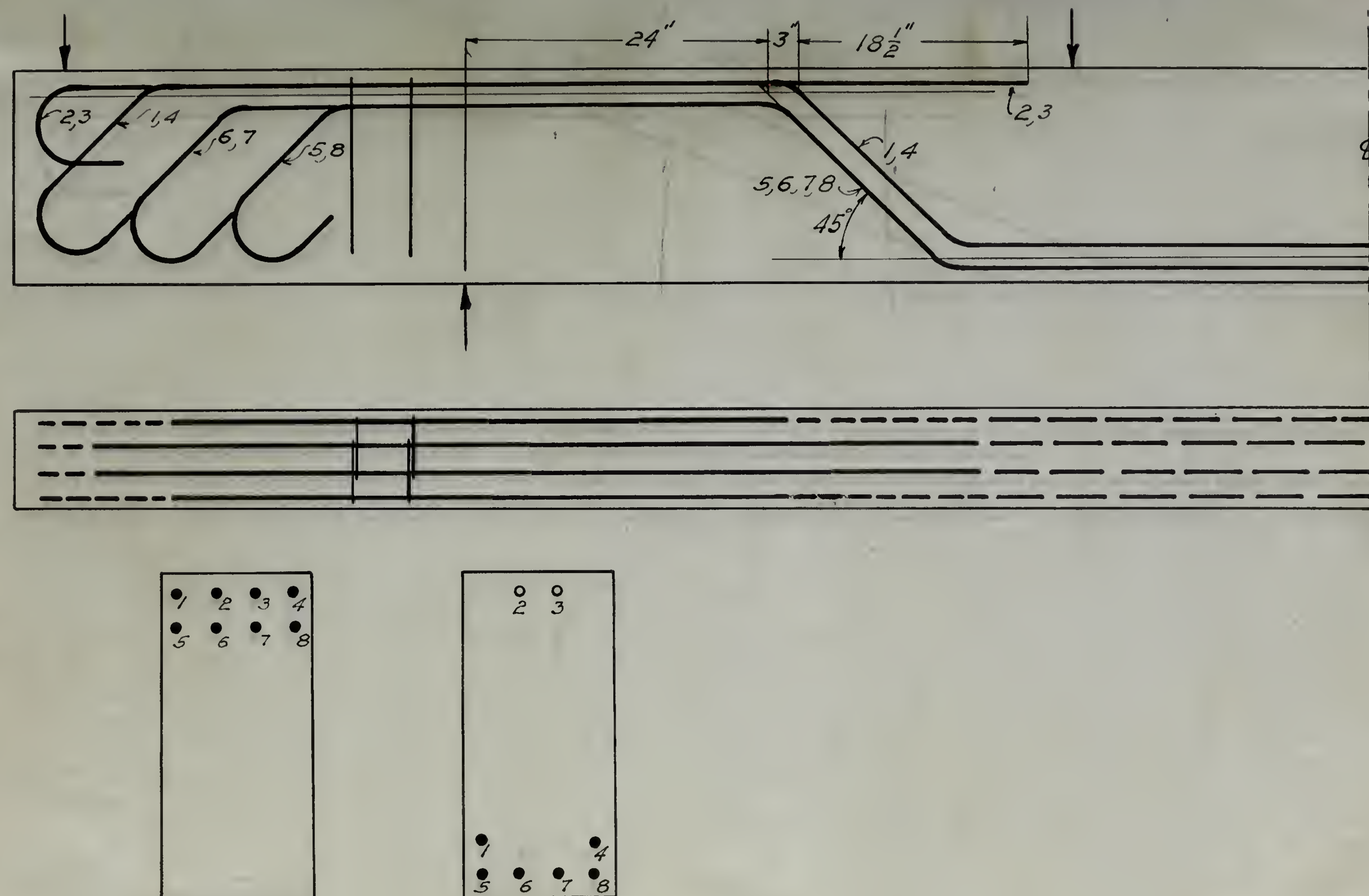
Supports and load points as shown.

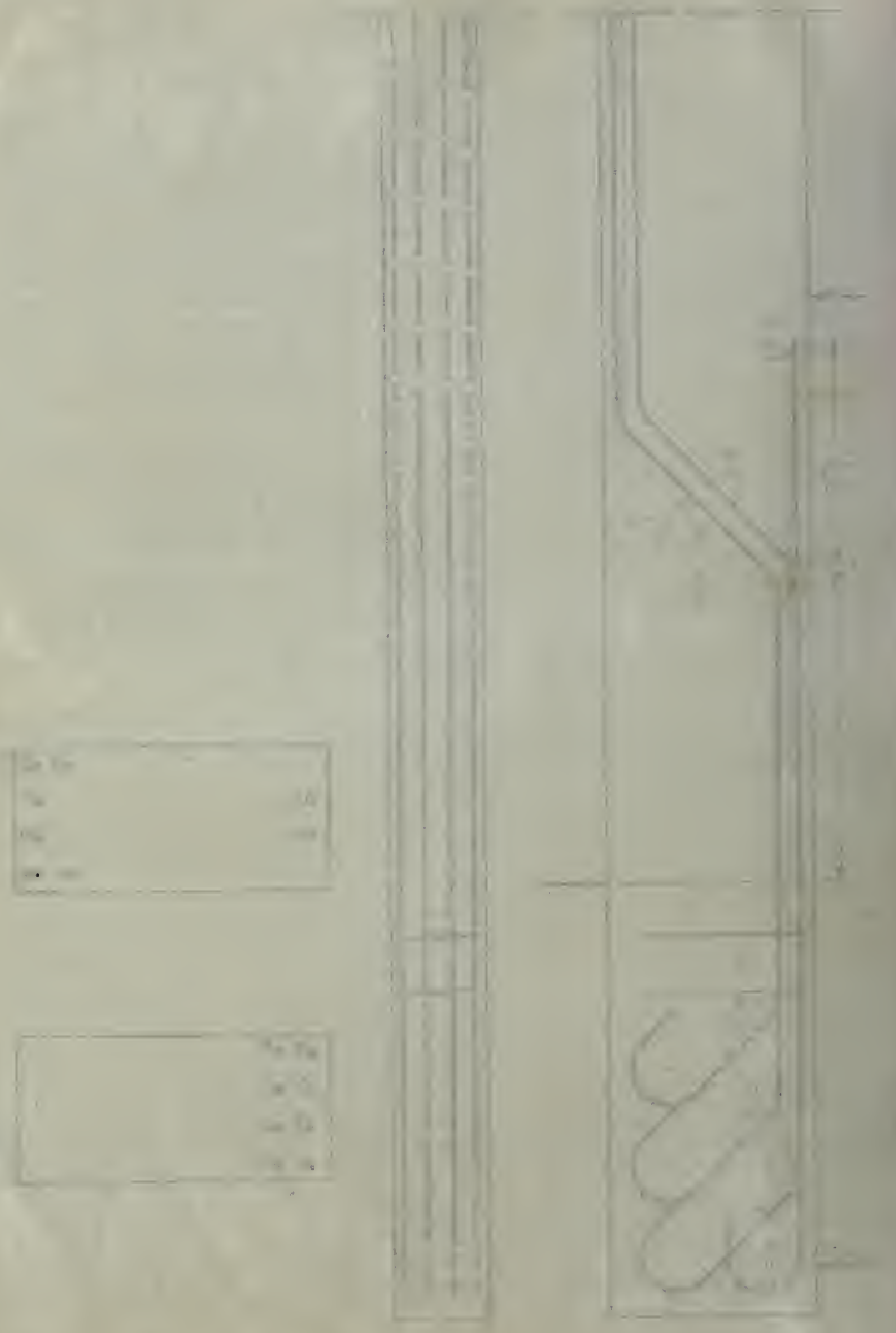
Sections AA & BB taken at same points for all beams.

Longitudinal reinforcement 5/8" ϕ bars

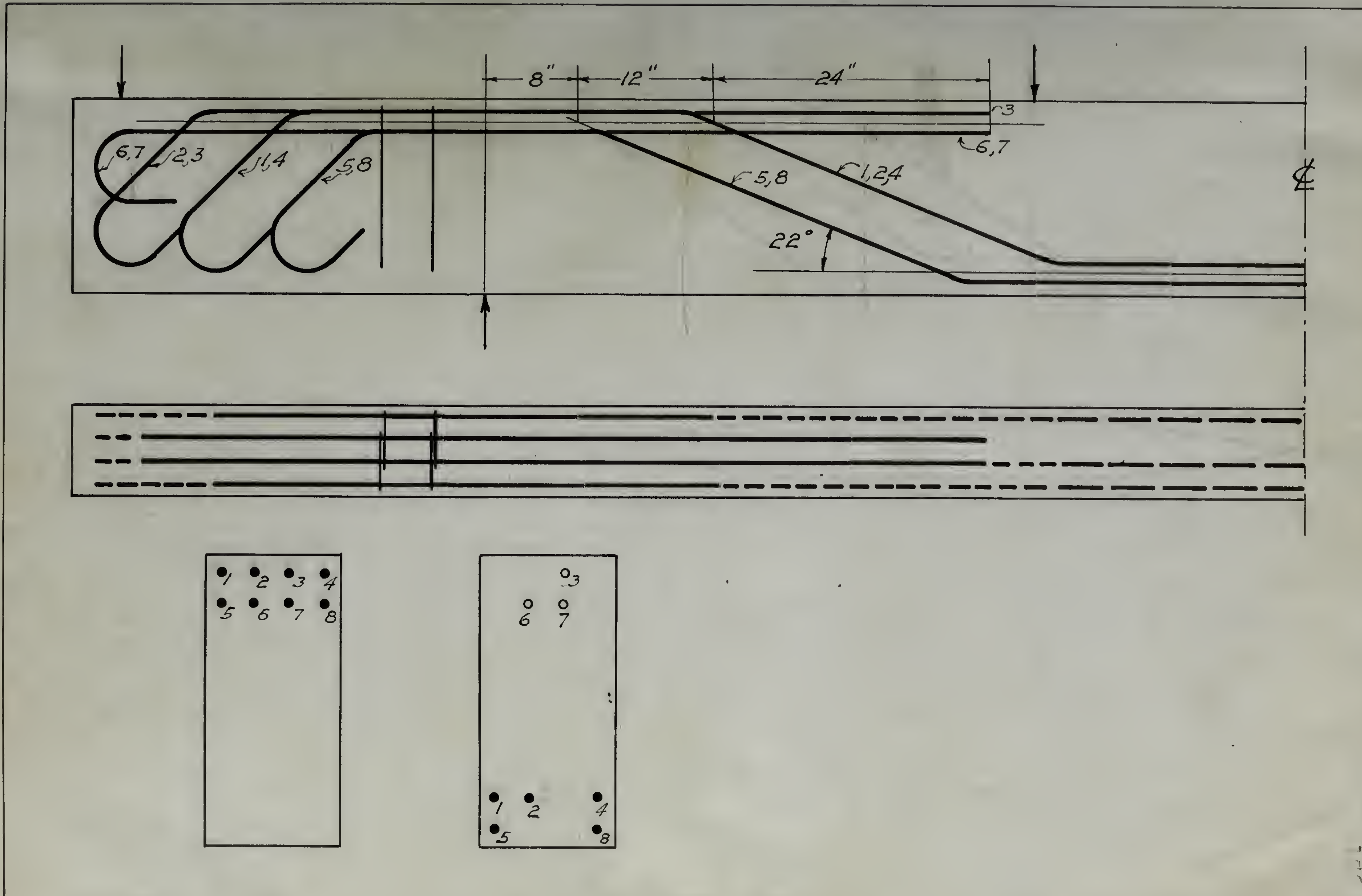
Stirrup reinforcement 3/8" ϕ bars

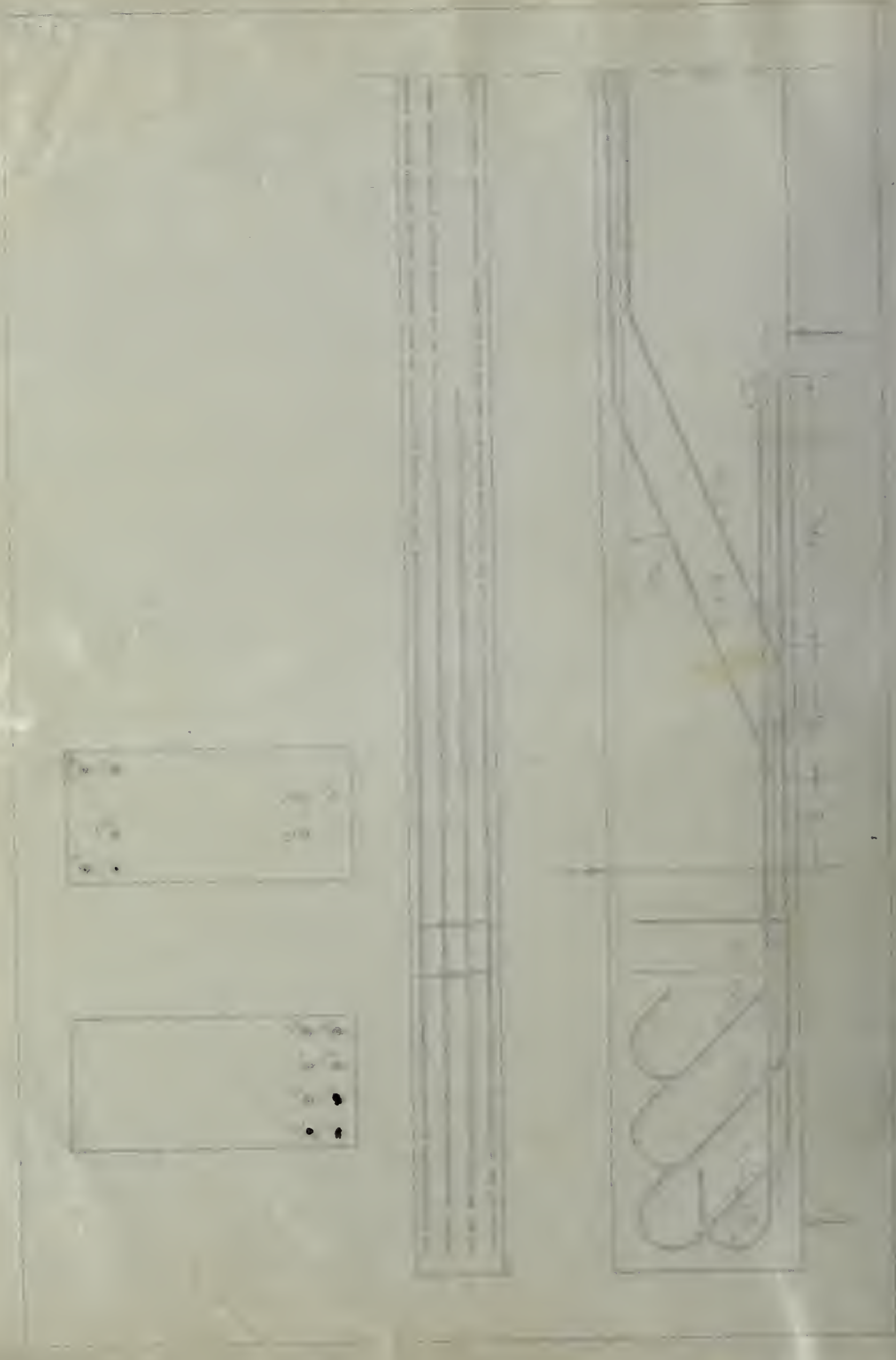
Beam 381



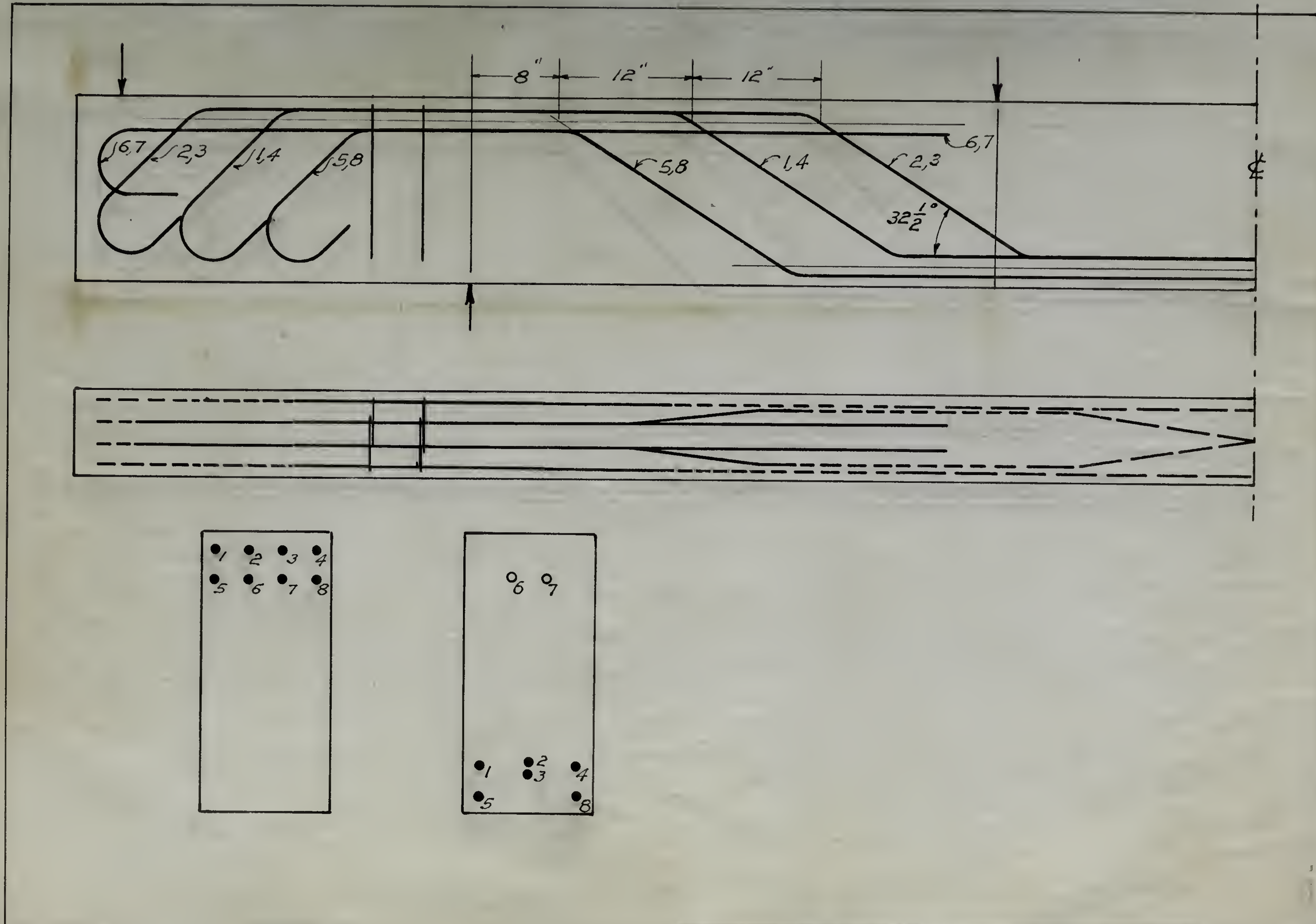


Beam 382

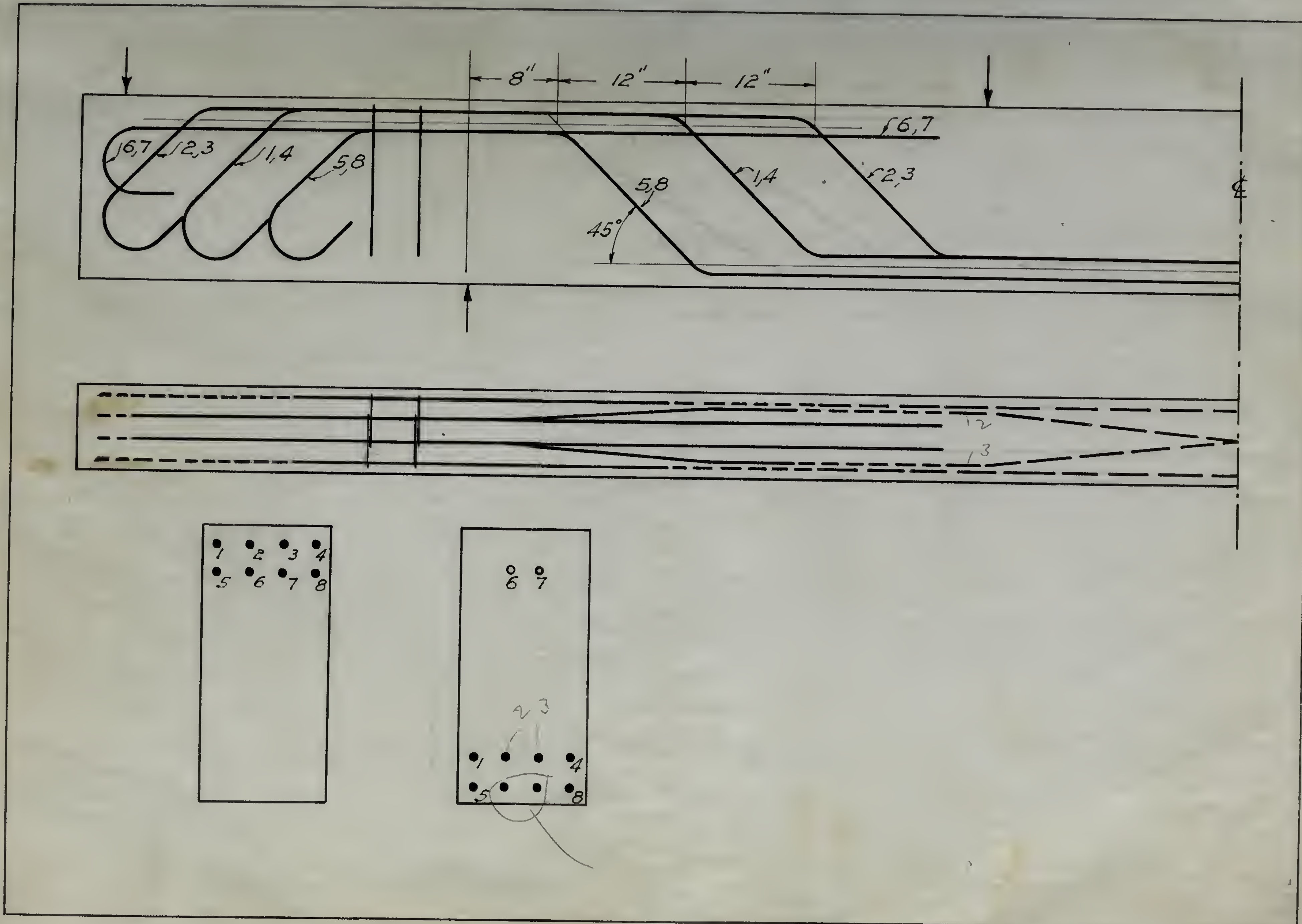


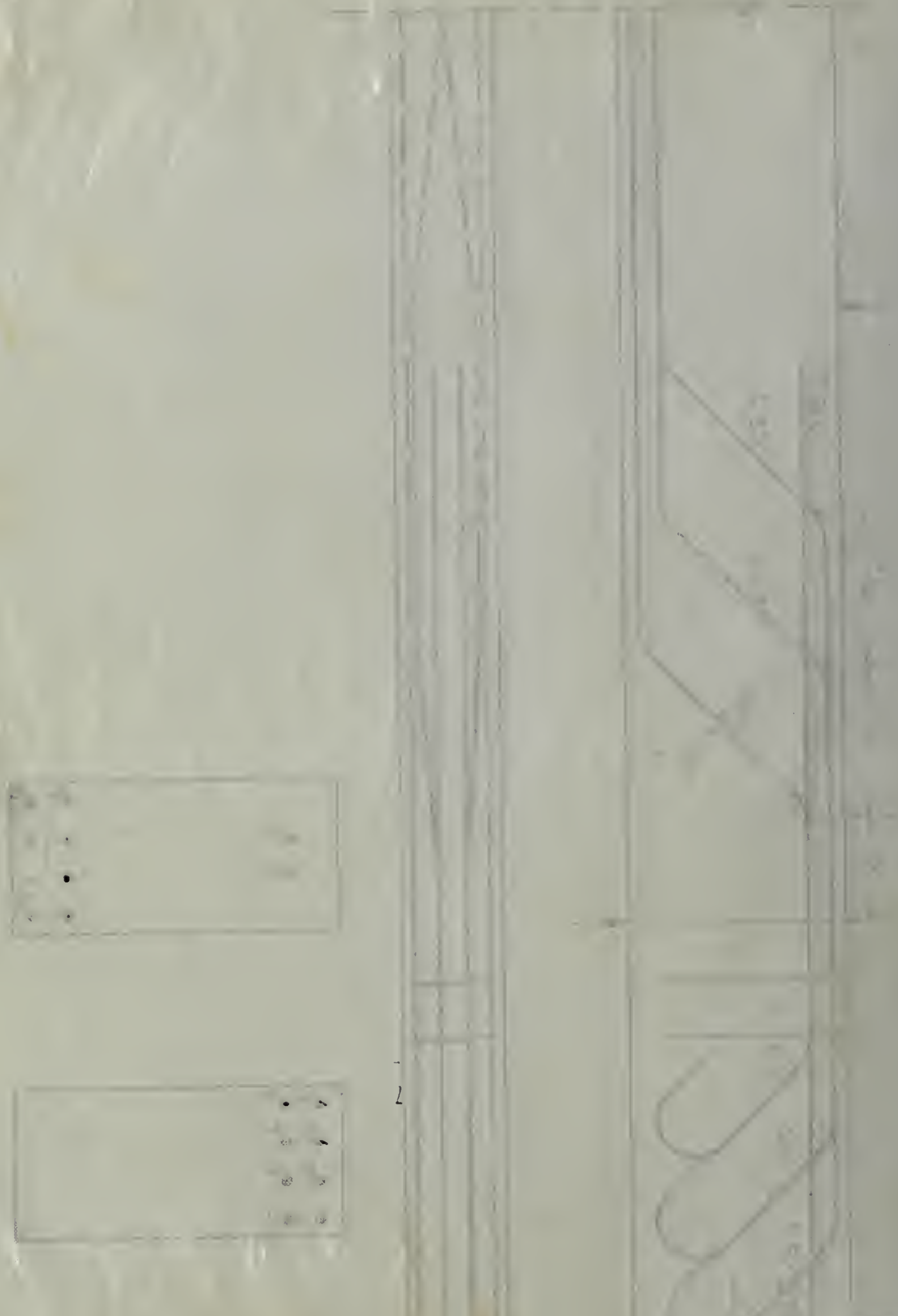


Beam 383

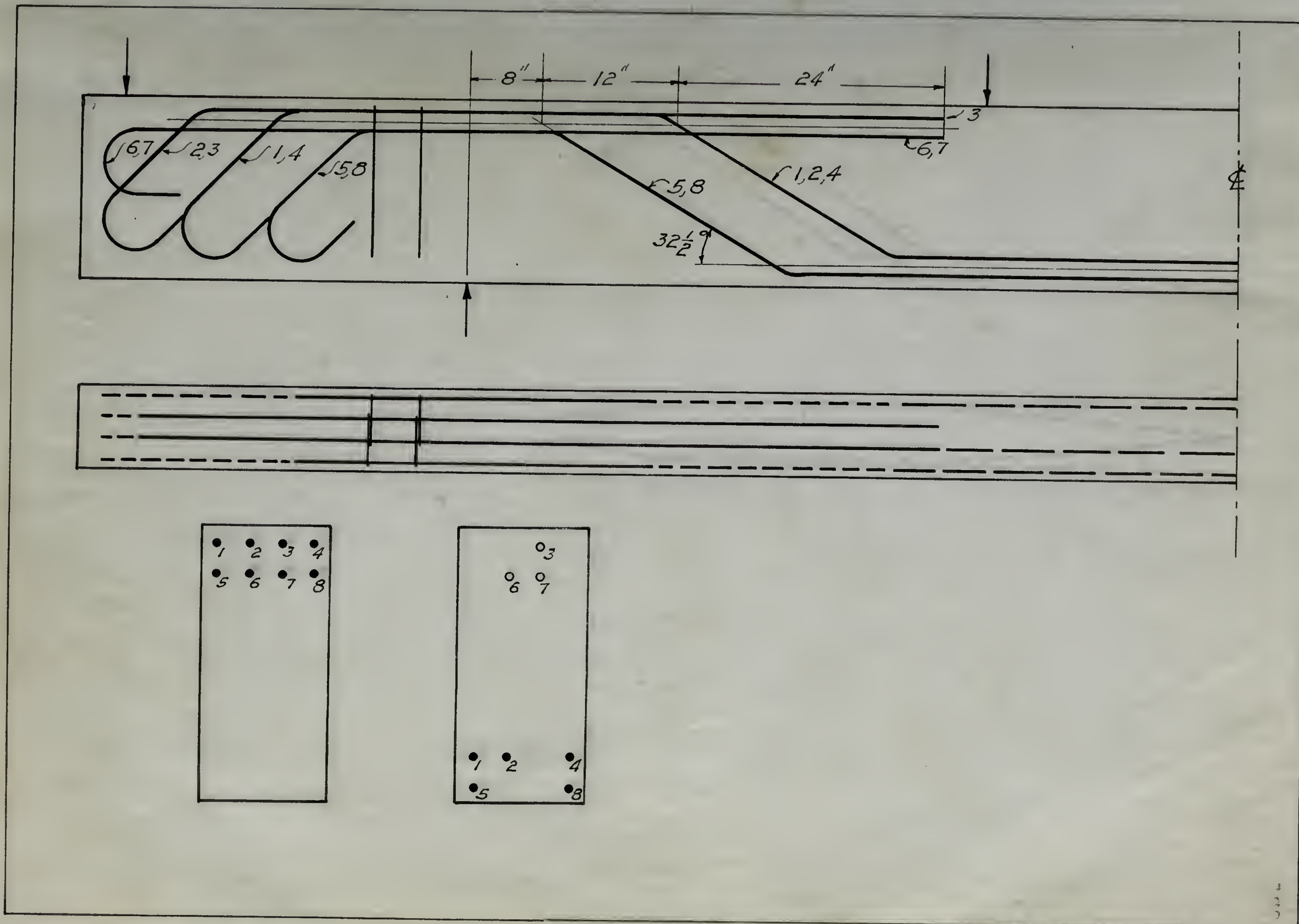


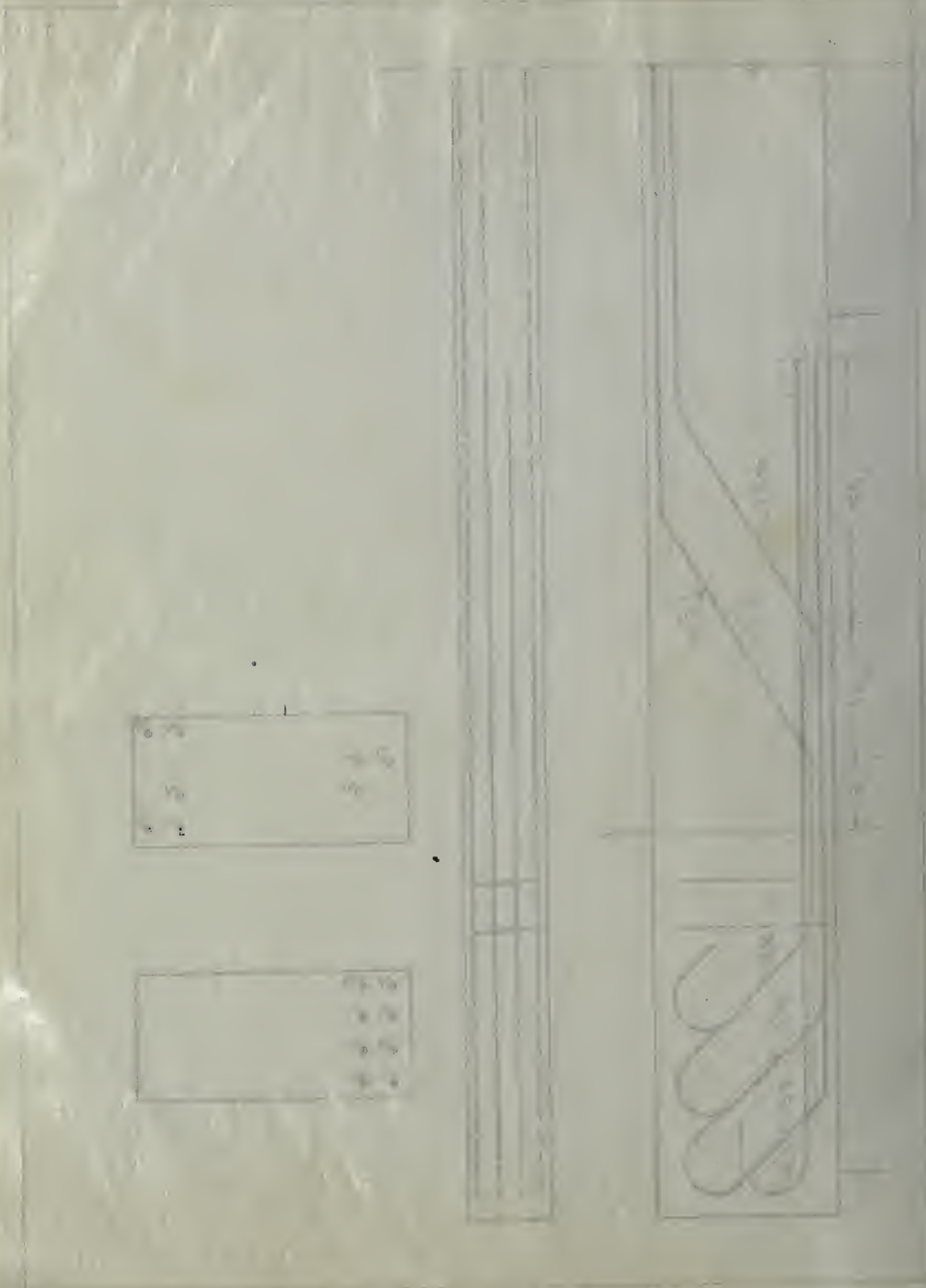
Beam 384



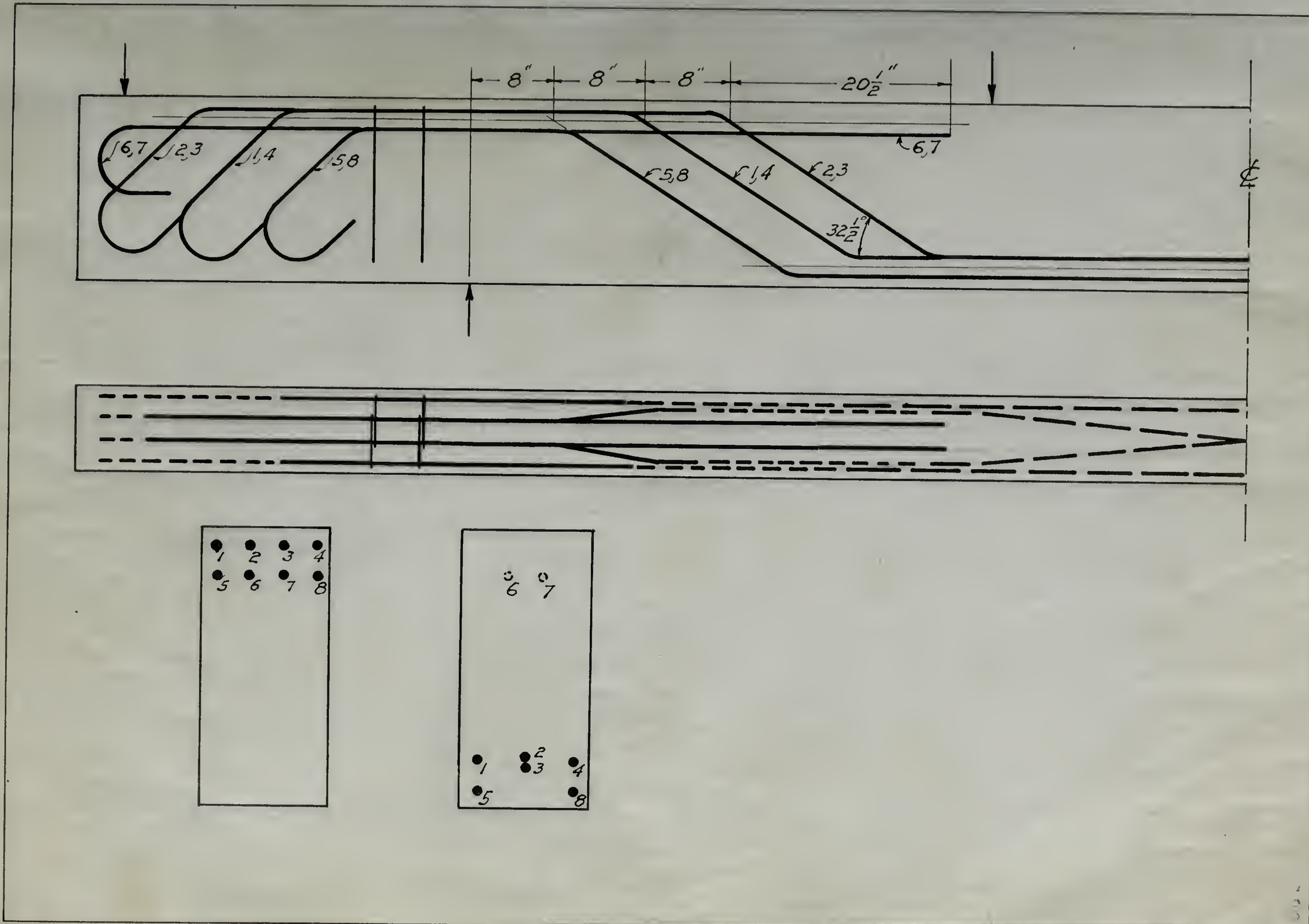


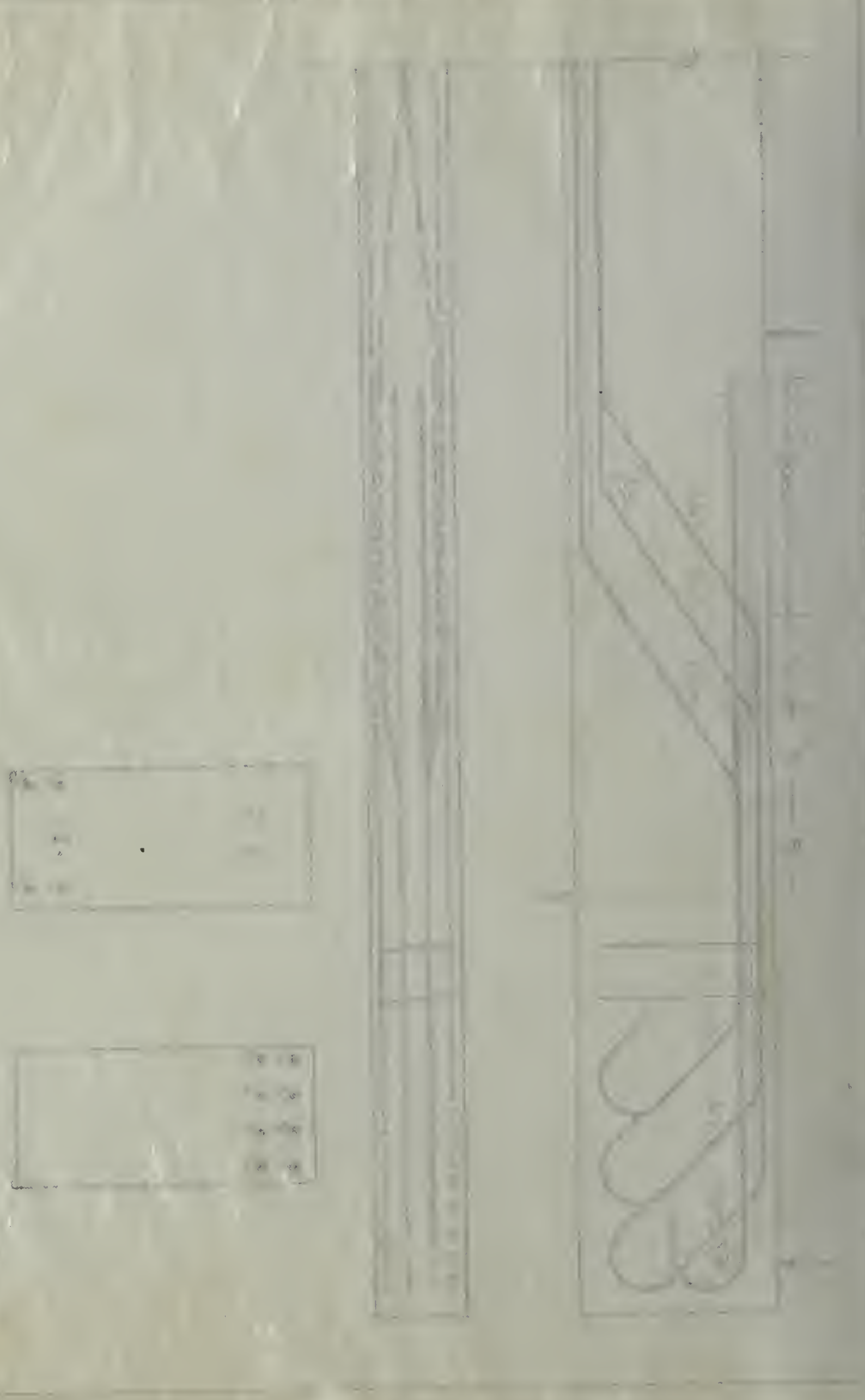
Beam 385



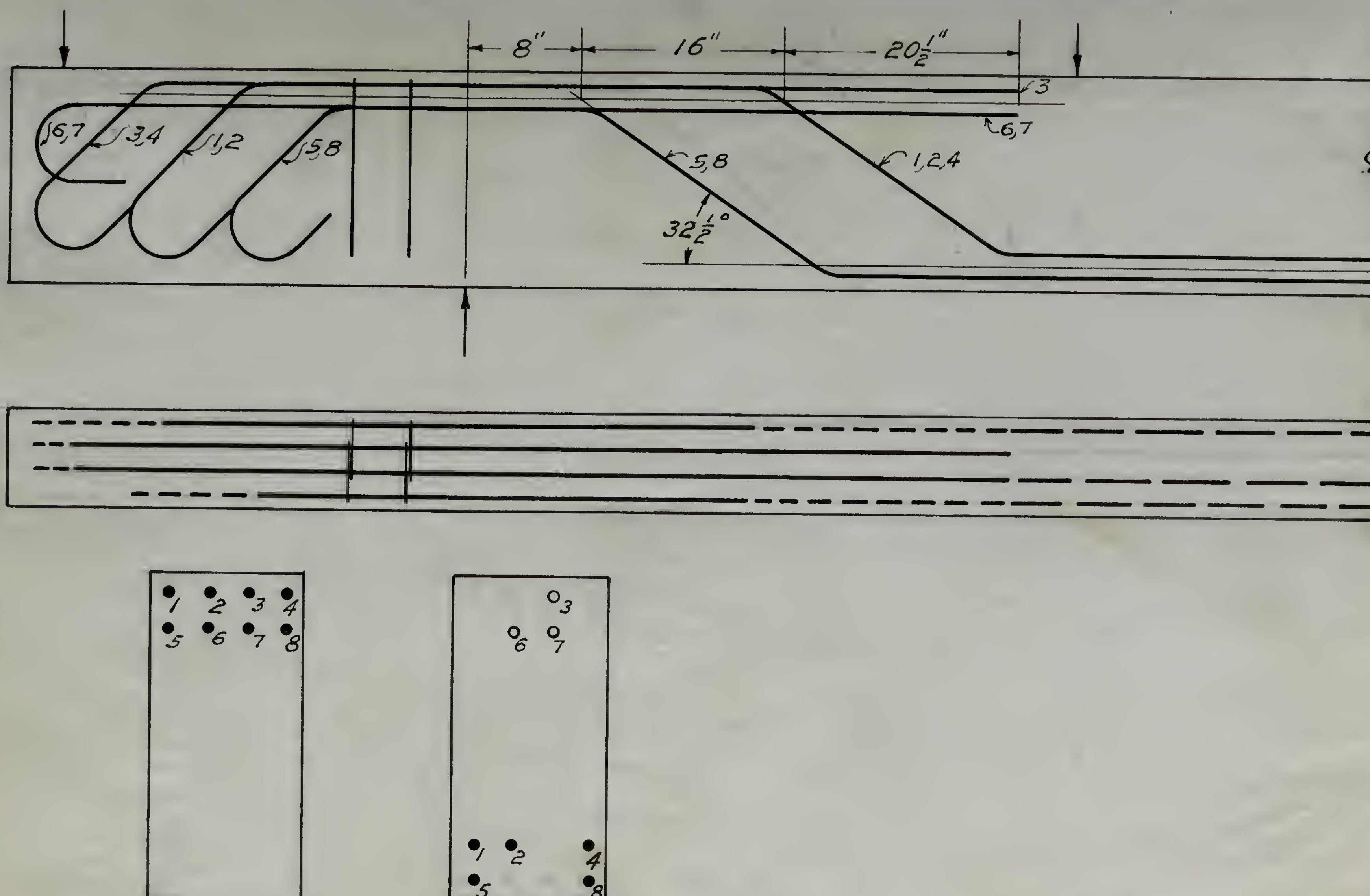


Beam 386

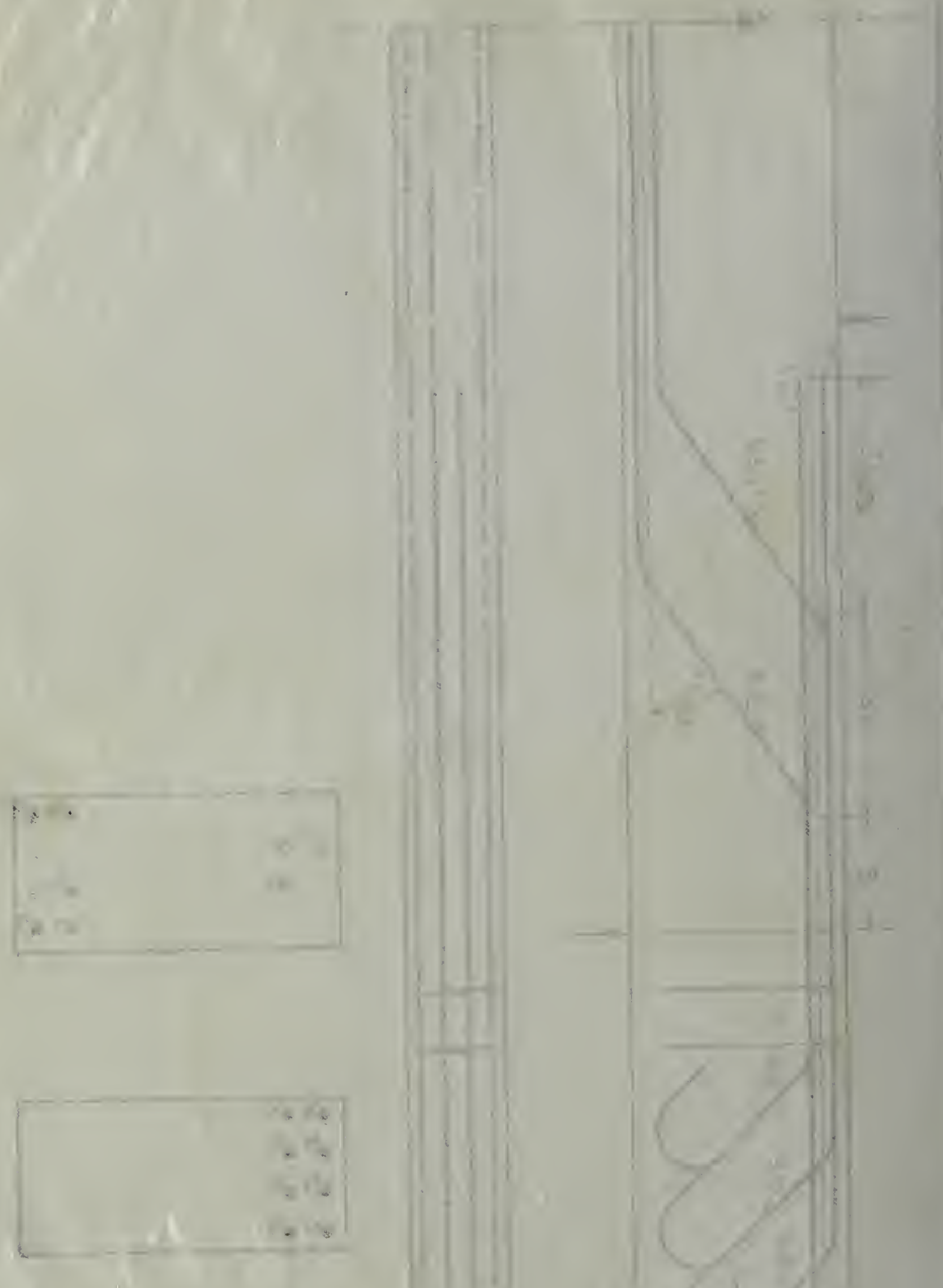




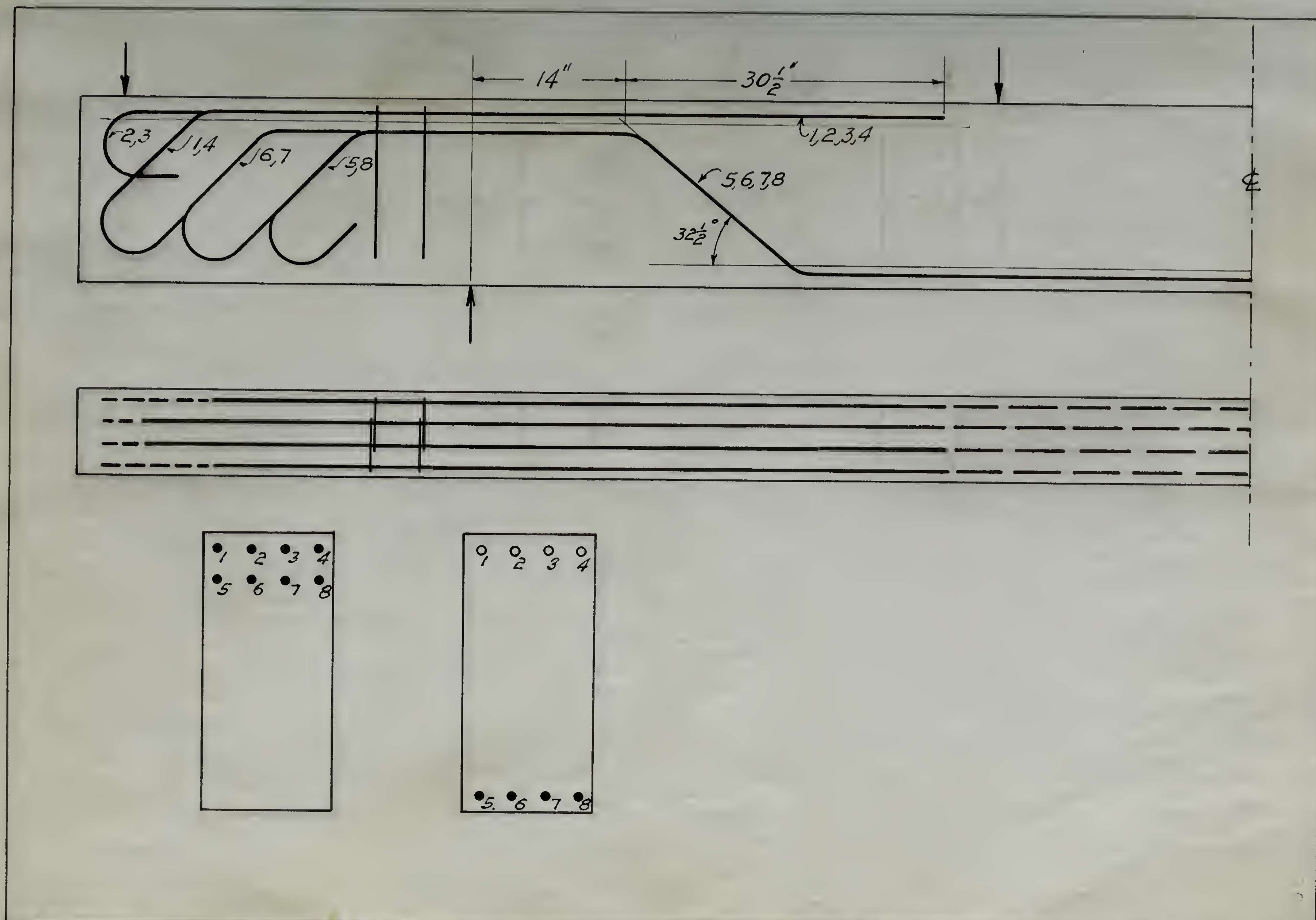
Beam 387



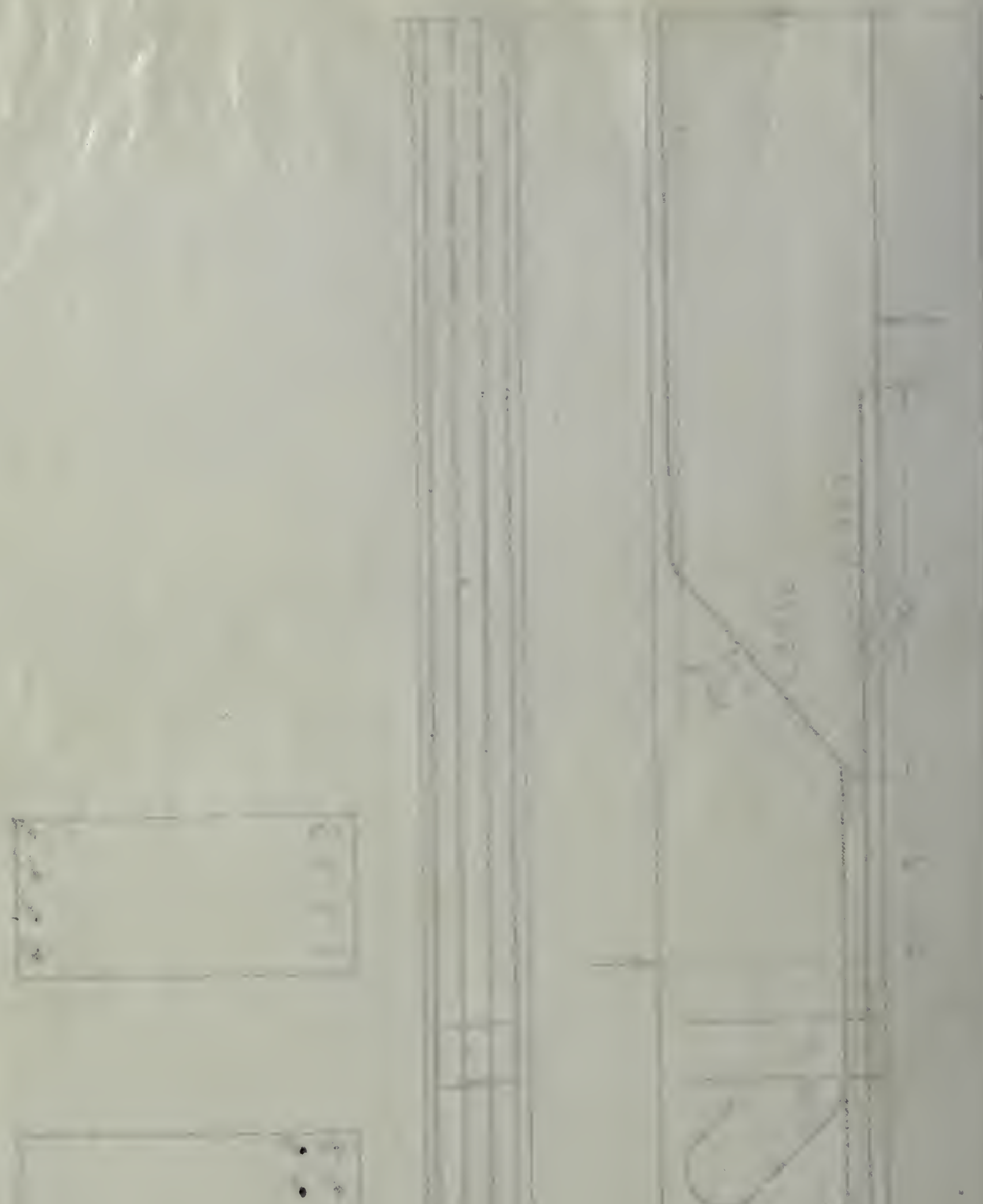
8"
16"
$20\frac{1}{2}$"
3
6,7
6,7
3,4
1,2
5,8
5,8
1,2,4
$32\frac{1}{2}°$
℄
1
2
3
4
5
6
7
8
3
6
7
1
2
4
5
8



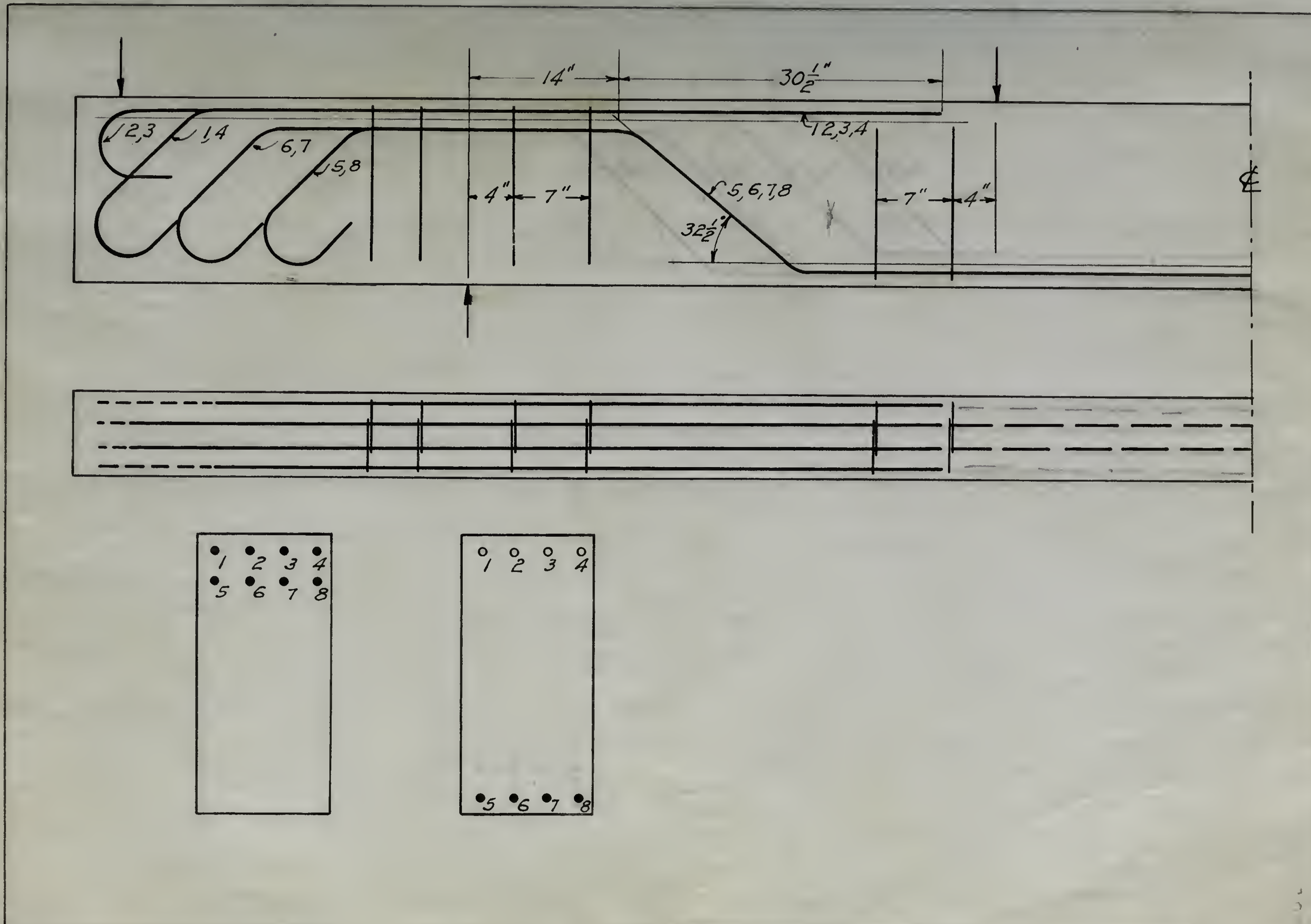
Beam 388



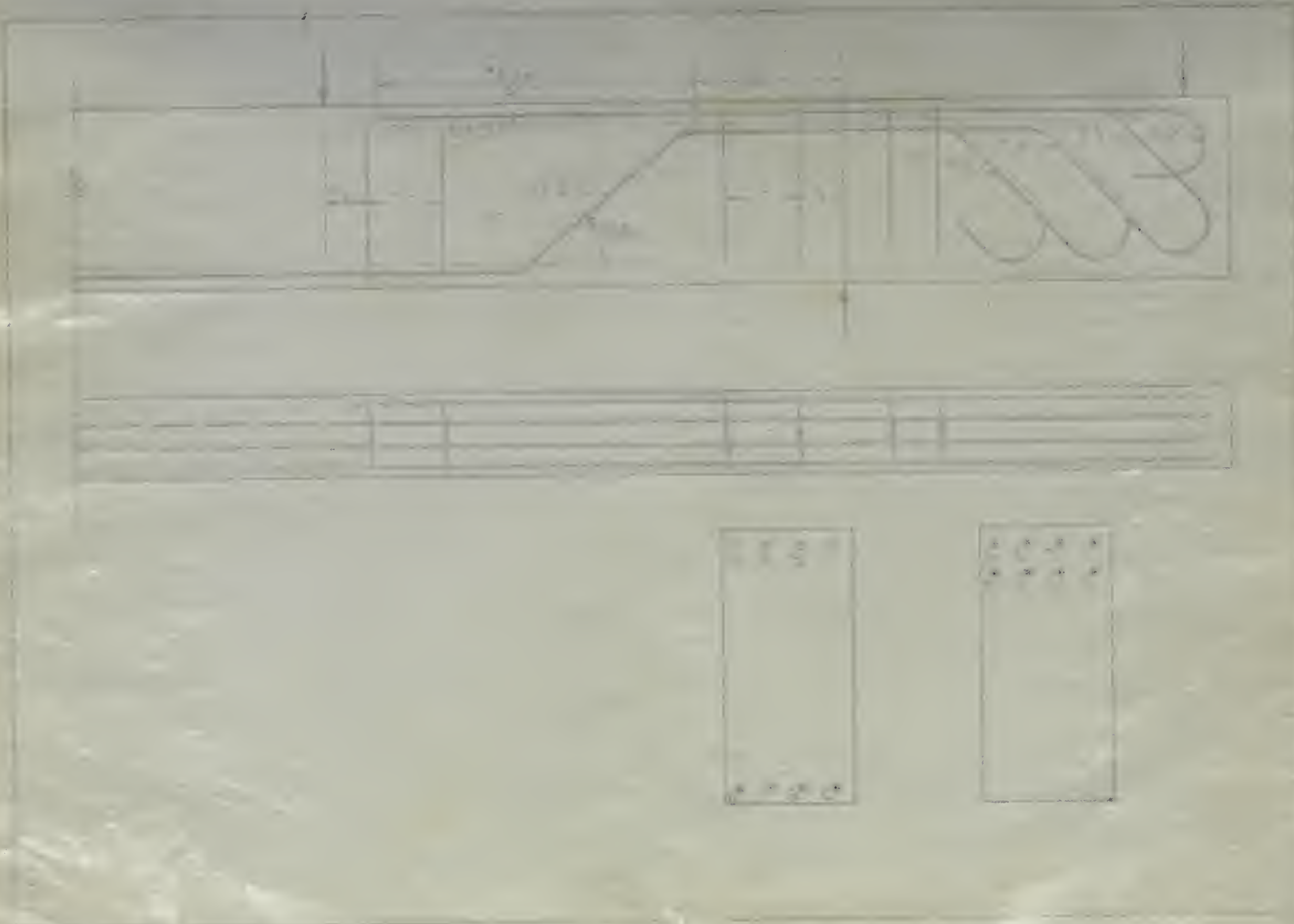
14"
$30\frac{1}{2}$"
2,3
1,4
6,7
5,8
1,2,3,4
5,6,7,8
$32\frac{1}{2}$°
℄
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8



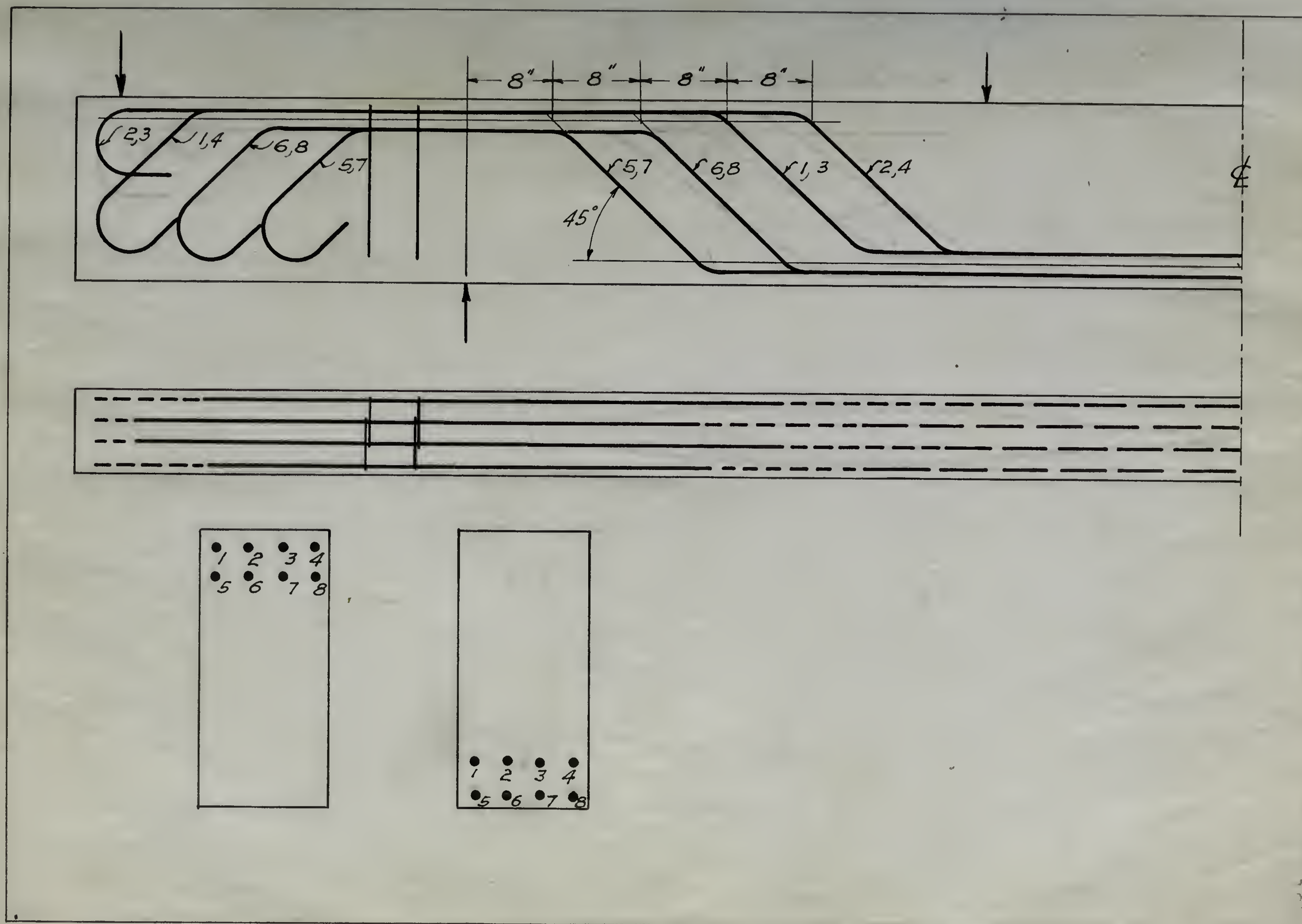
Beam 389



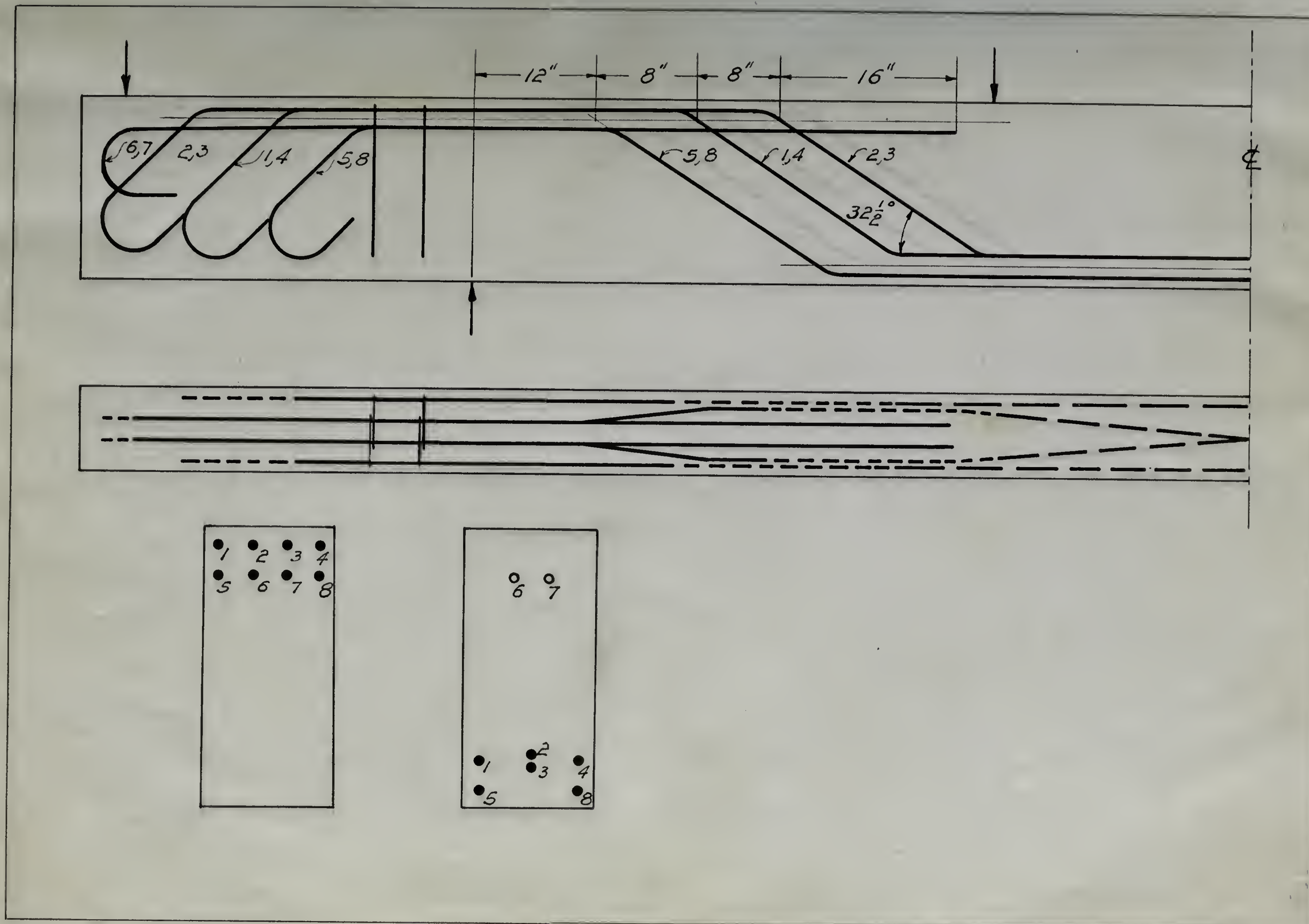
14"
$30\frac{1}{2}$"
2,3
1,4
6,7
5,8
1,2,3,4
5,6,7,8
$32\frac{1}{2}$°
4"
7"
7"
4"
℄
1 2 3 4
5 6 7 8
1 2 3 4
5 6 7 8

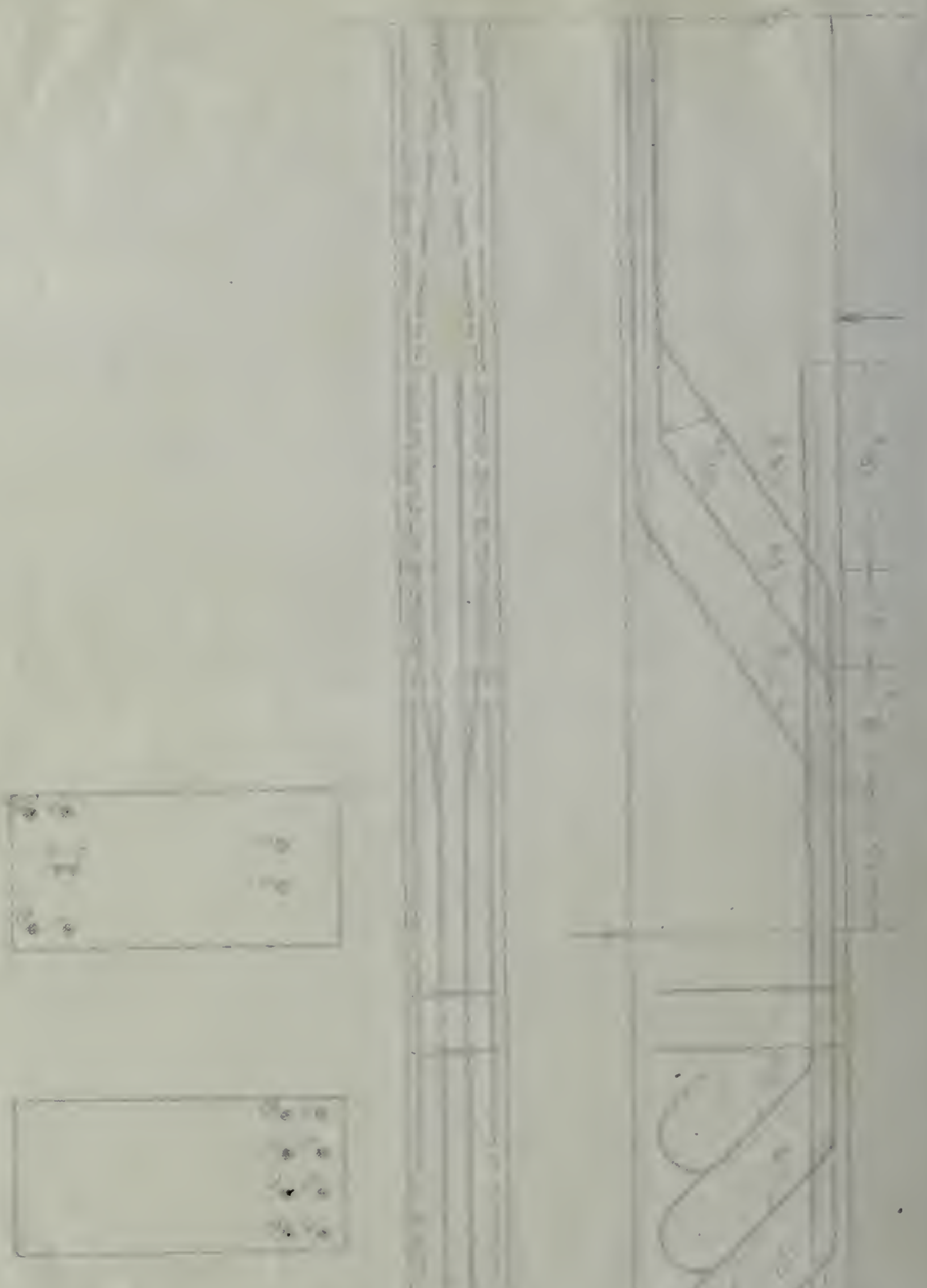


Beam 390

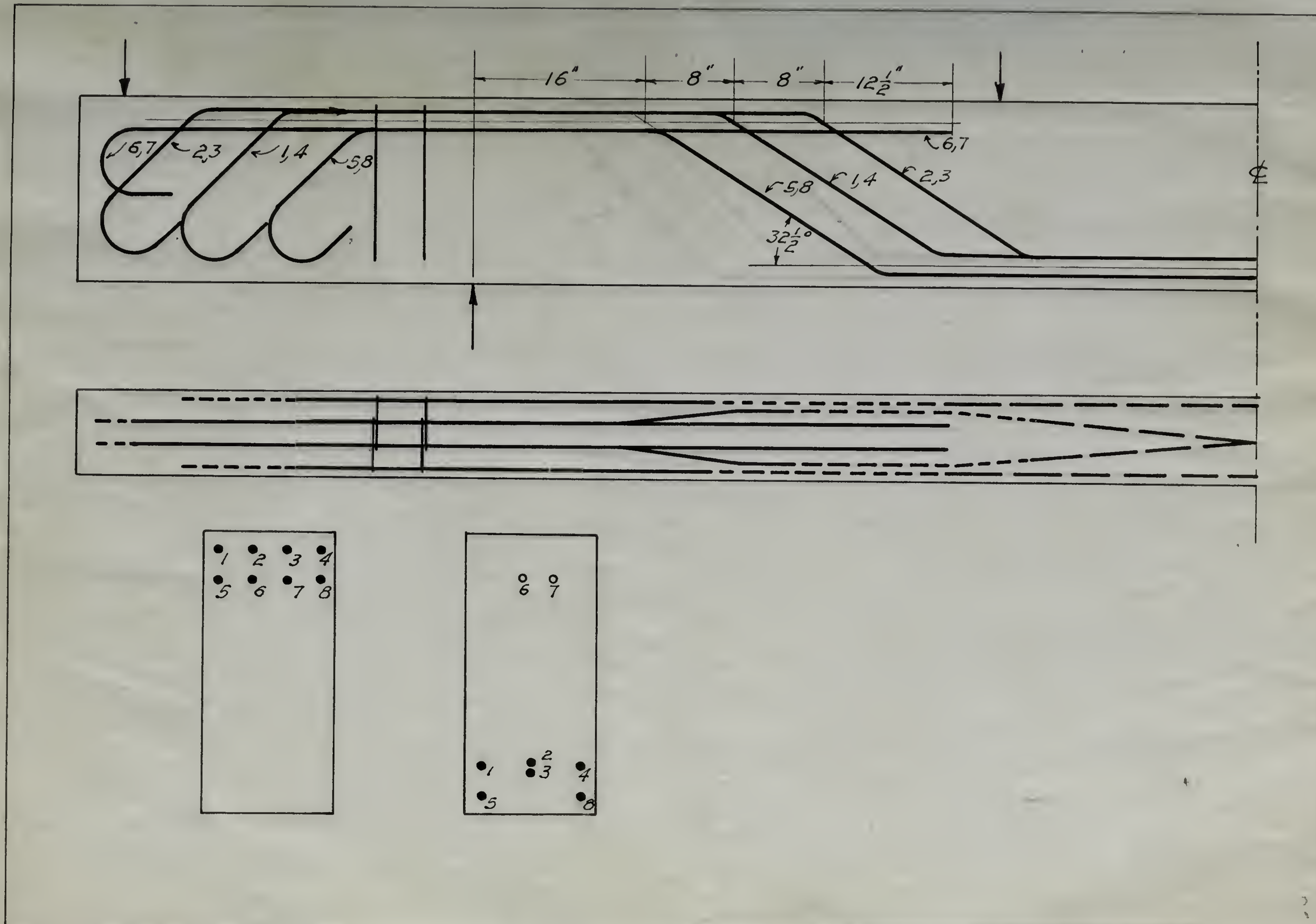


Beam 391

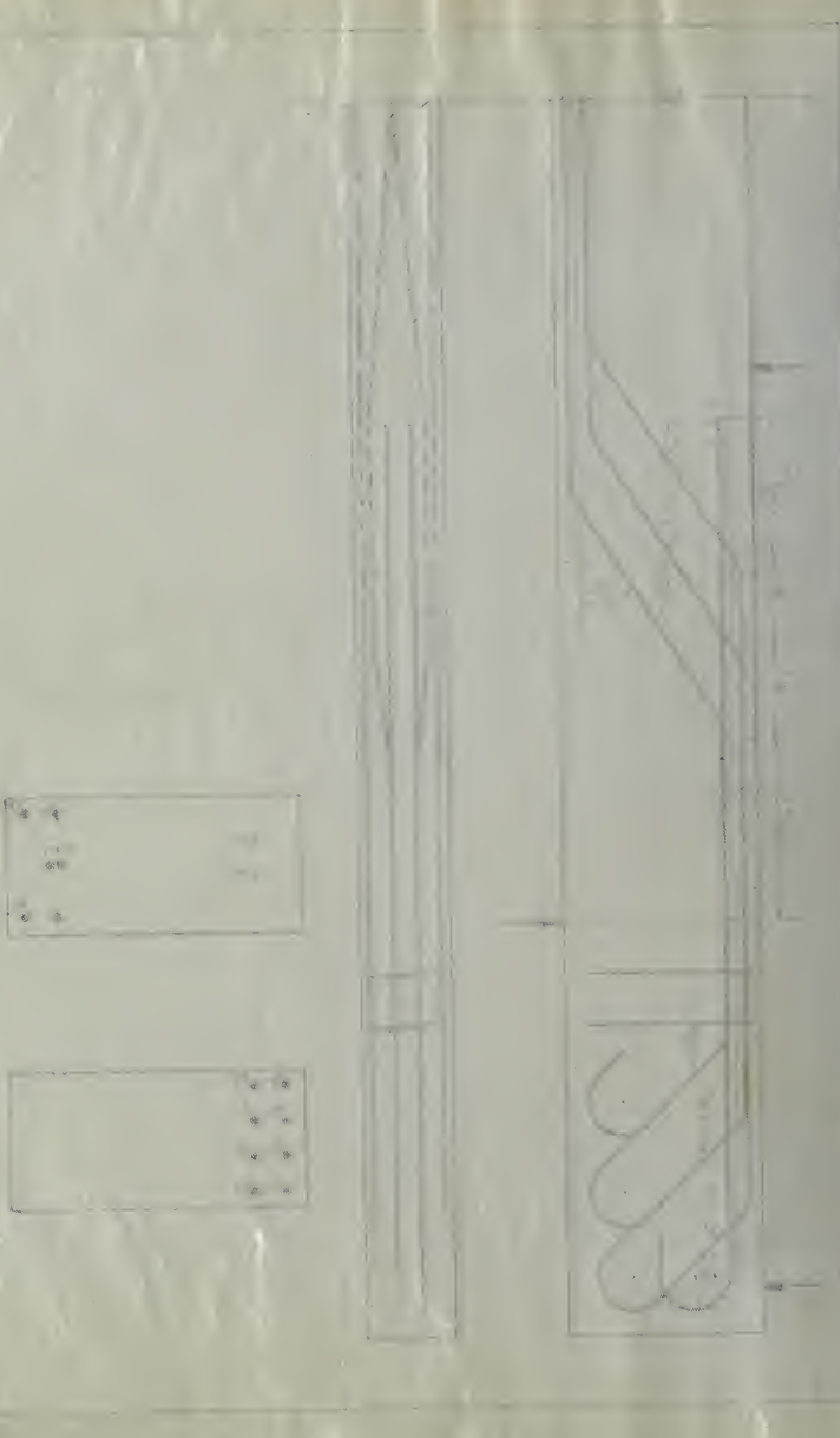




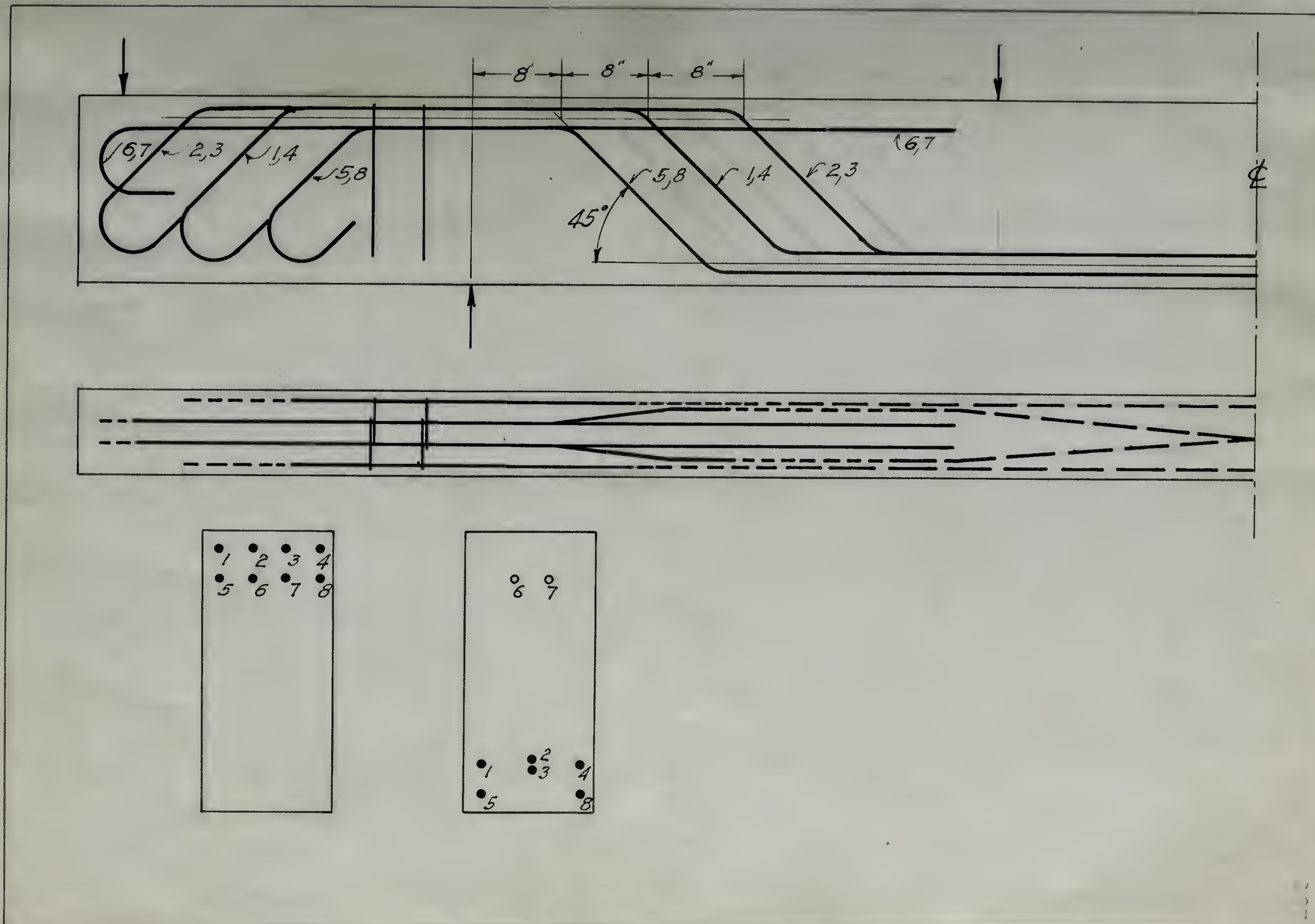
Beam 392

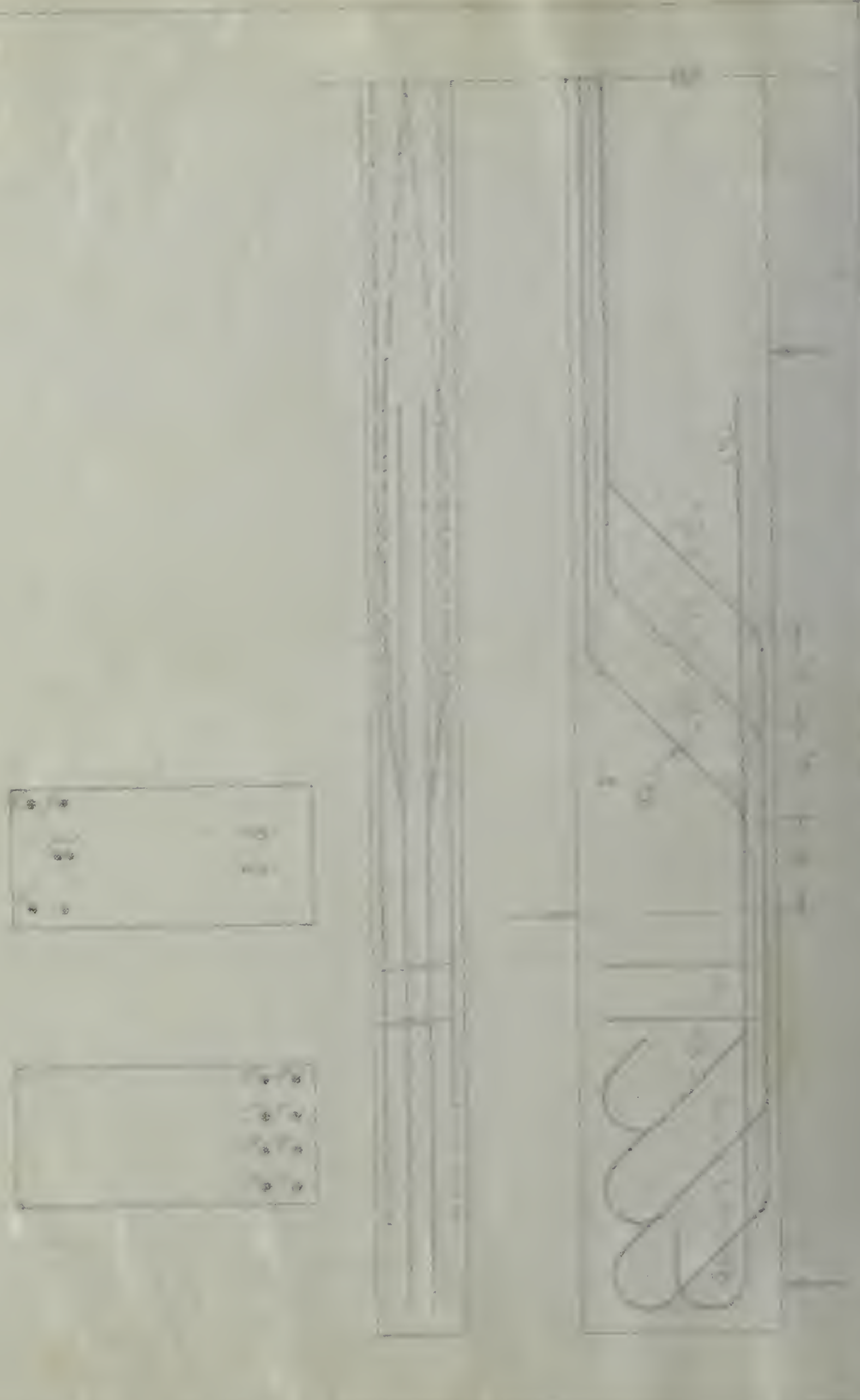


16"
8"
8"
$12\frac{1}{2}$"
6,7
2,3
1,4
5,8
6,7
2,3
1,4
5,8
$32\frac{1}{2}$°
℄
1 2 3 4
5 6 7 8
6 7
1 2 3 4
5 8

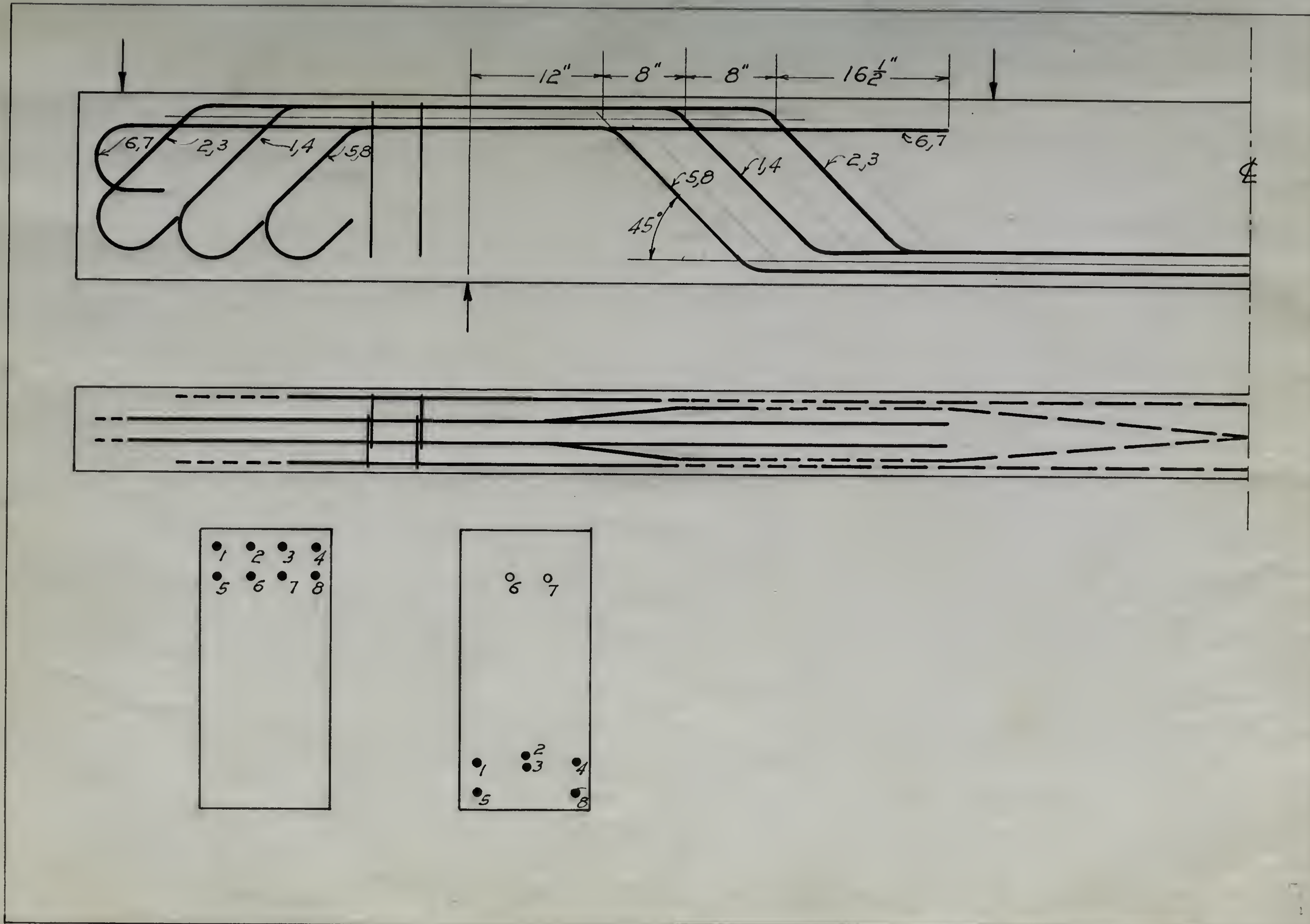


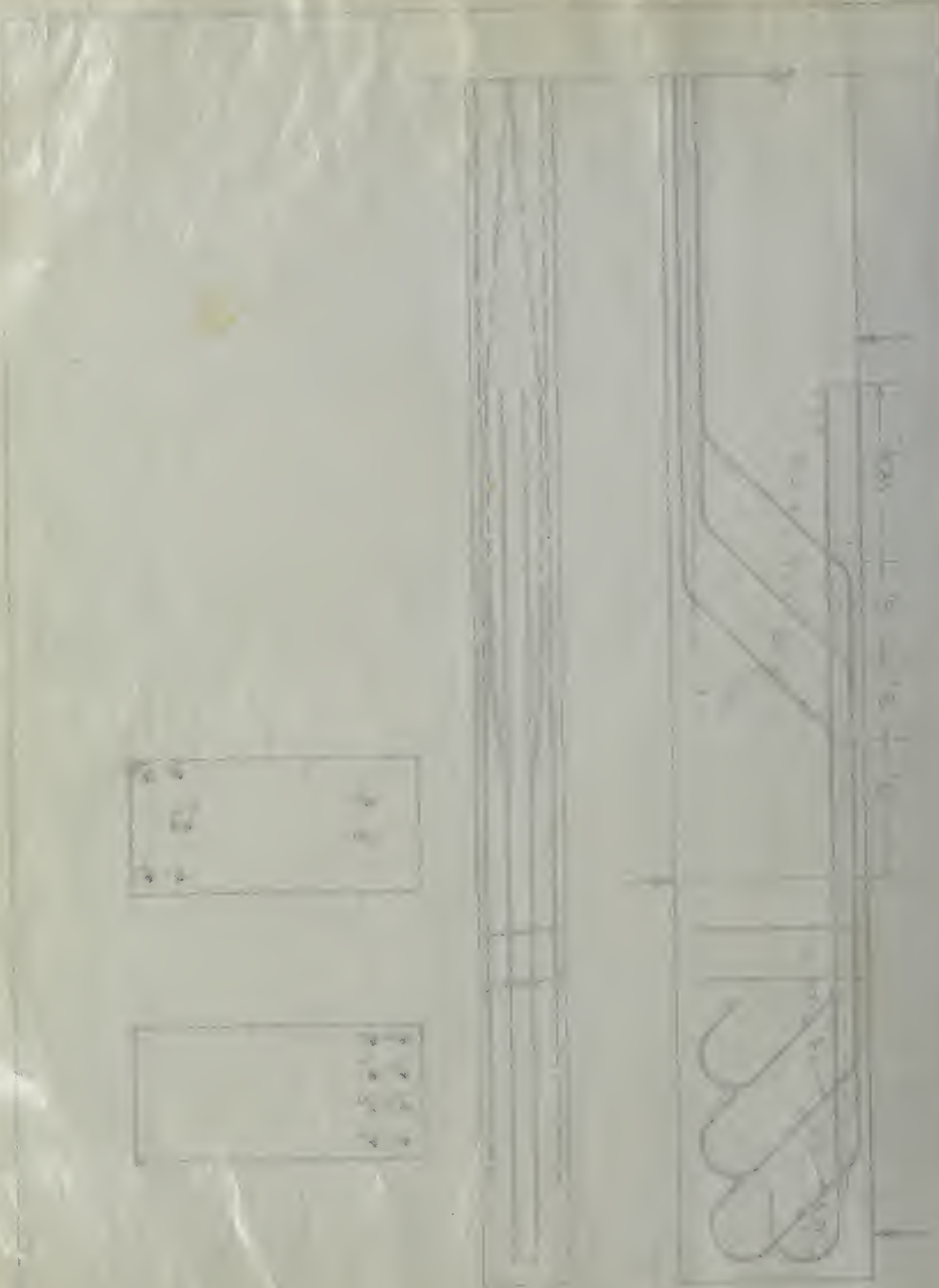
Beam 393



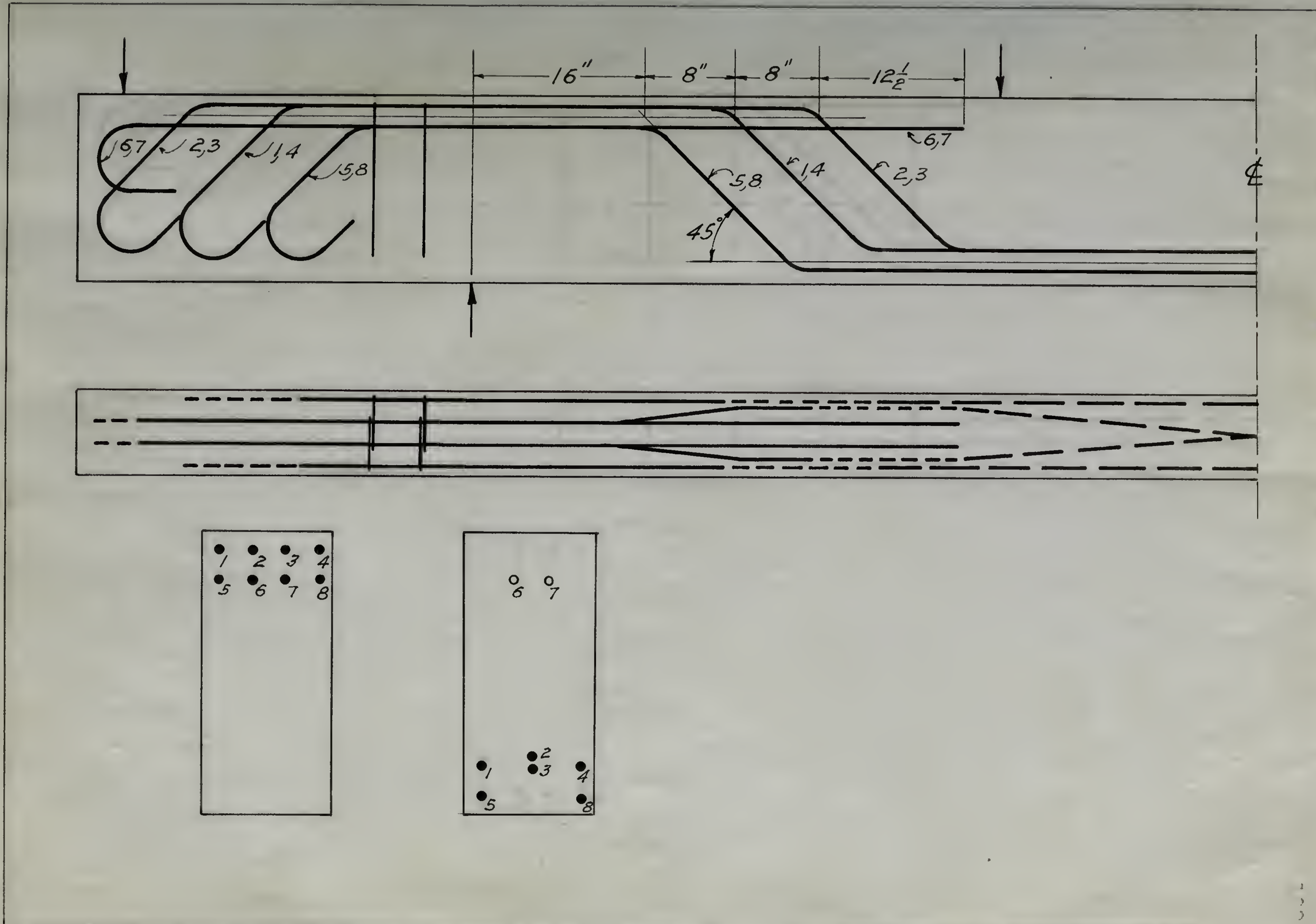


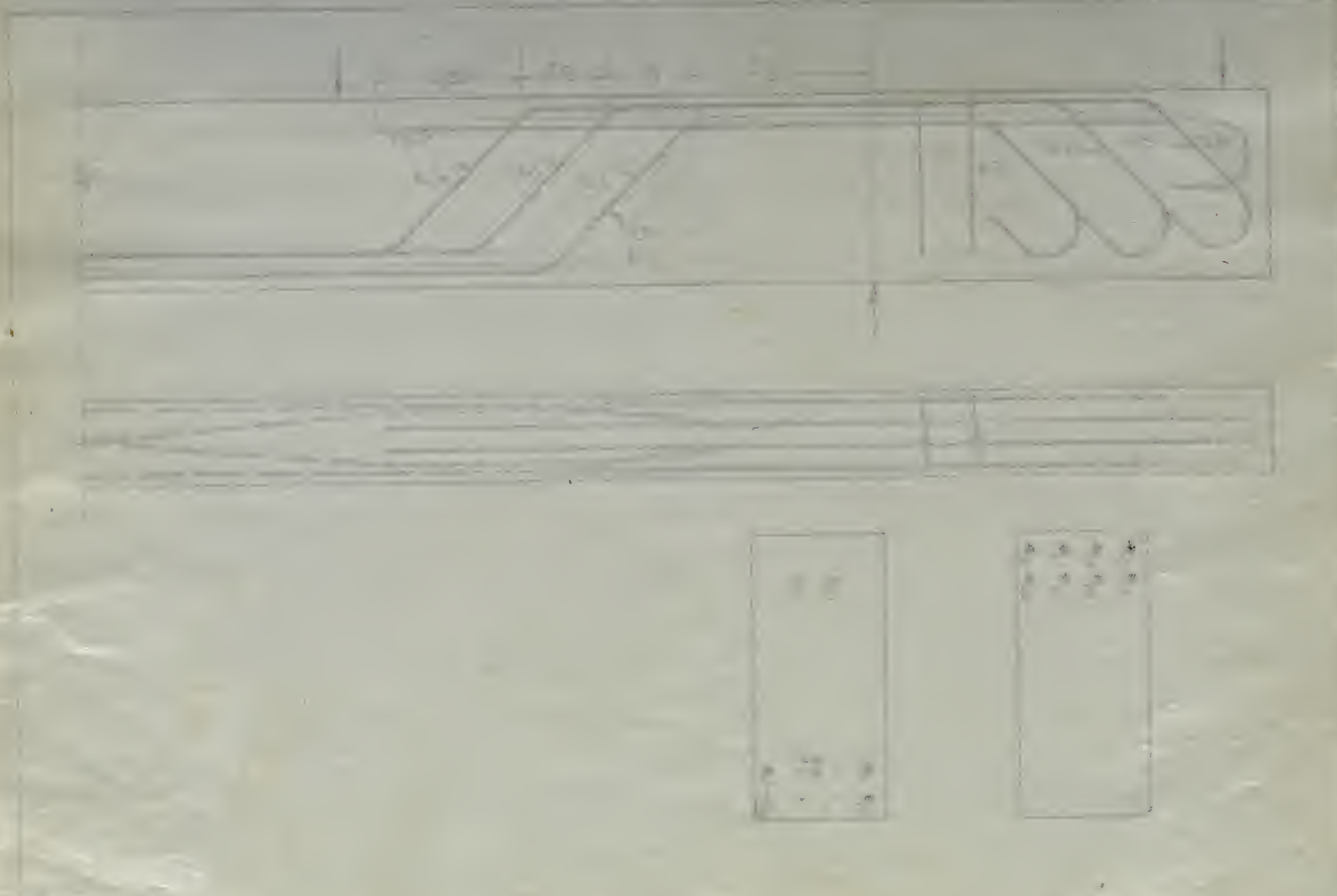
Beam 394



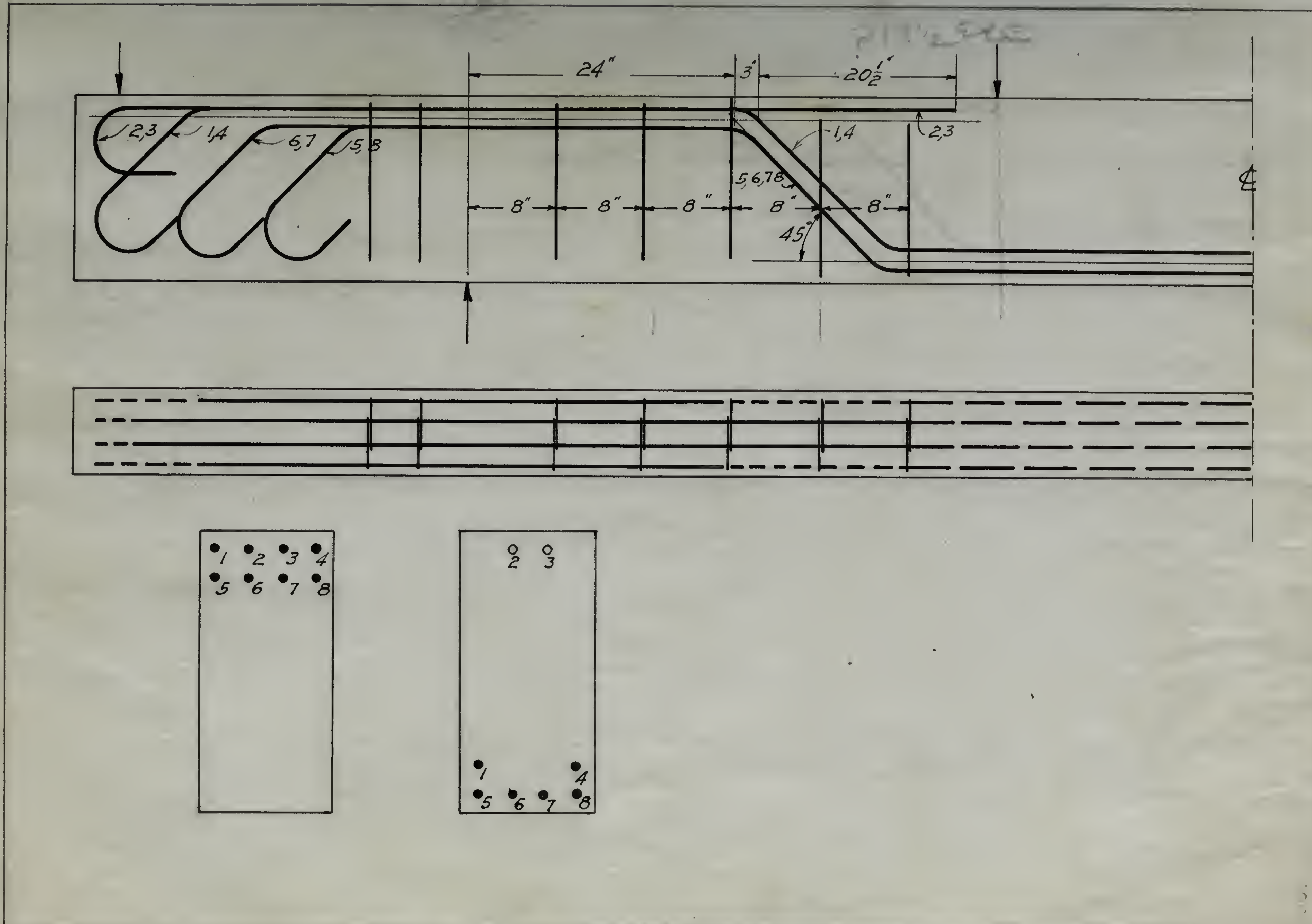


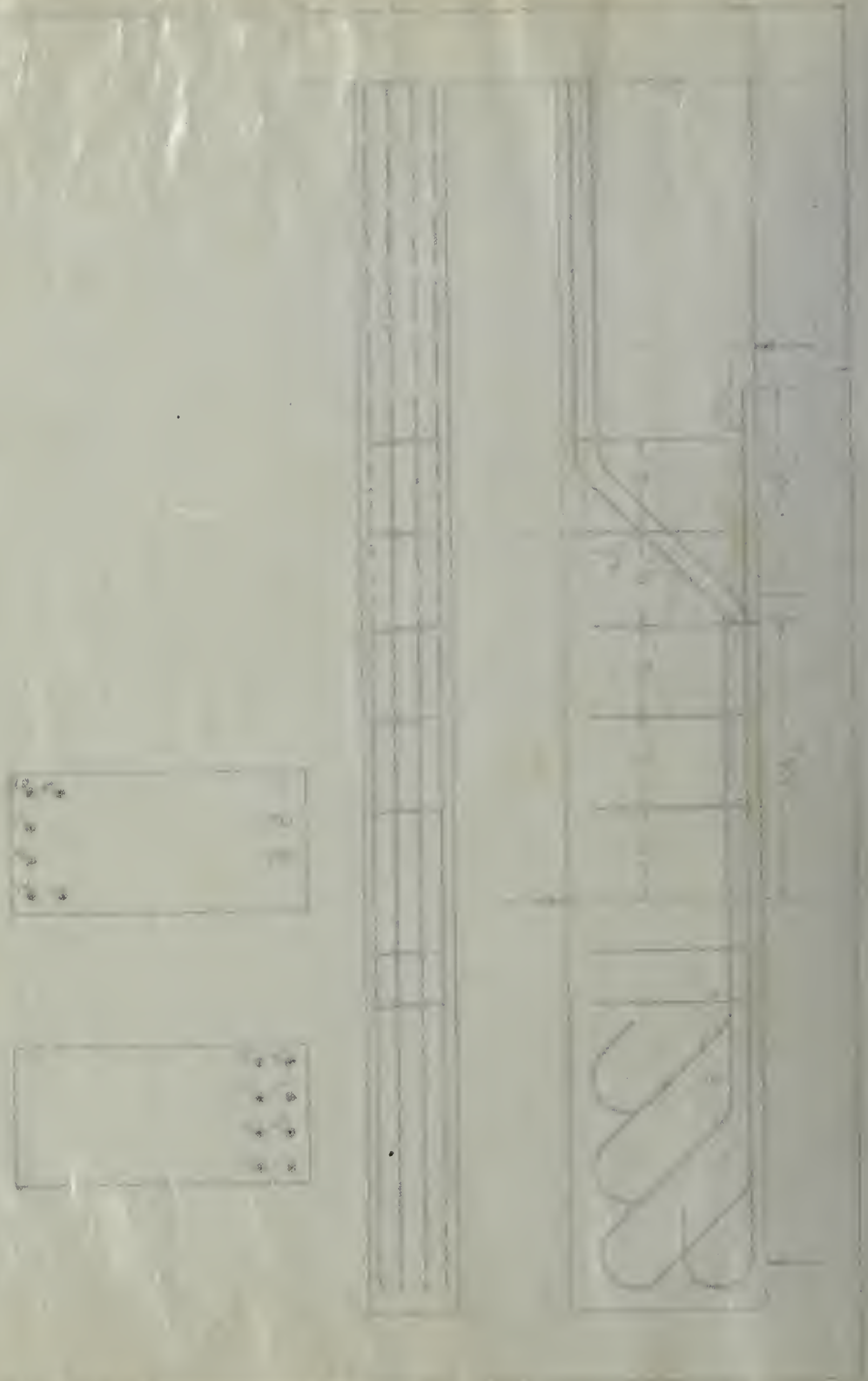
Beam 395



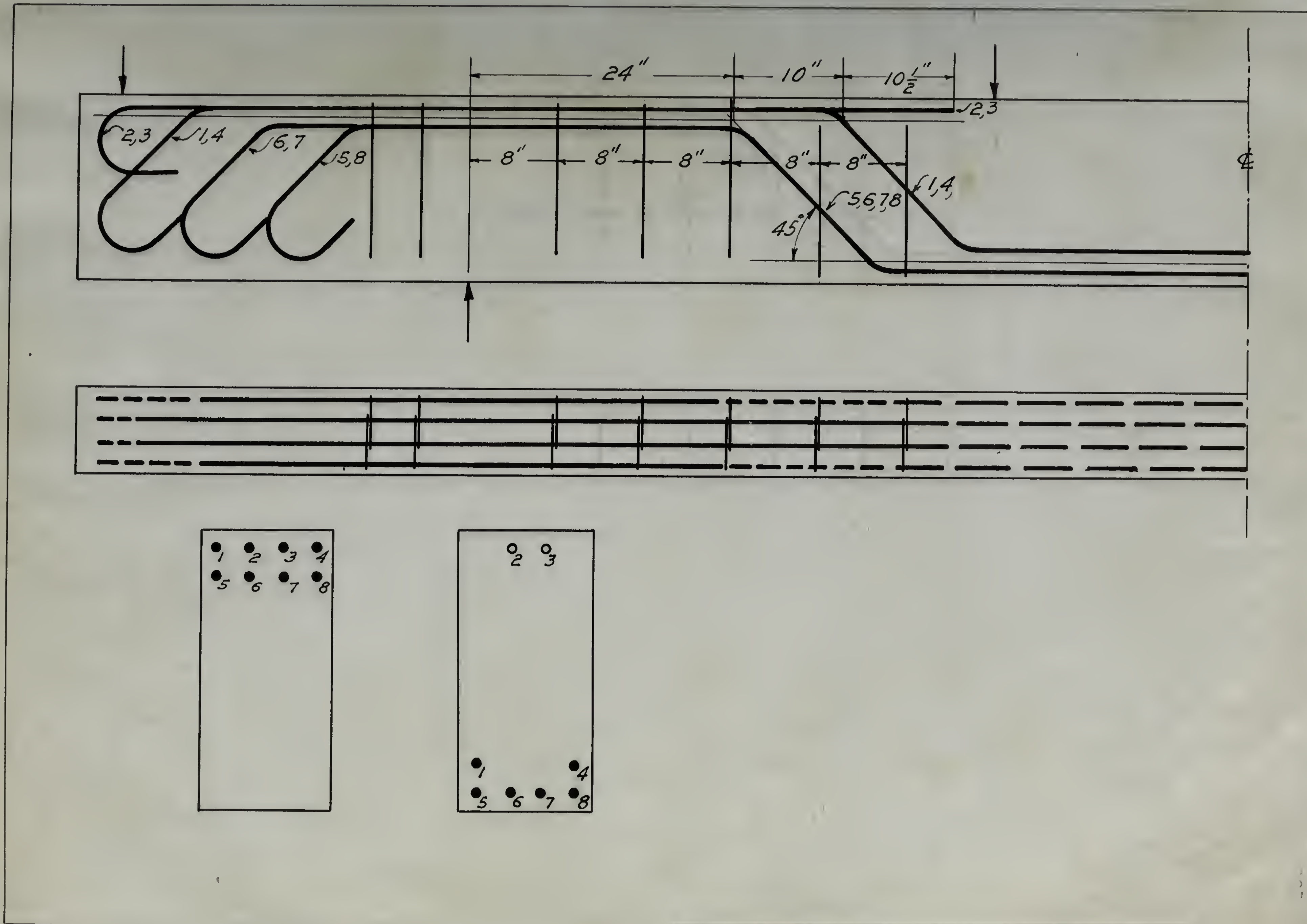


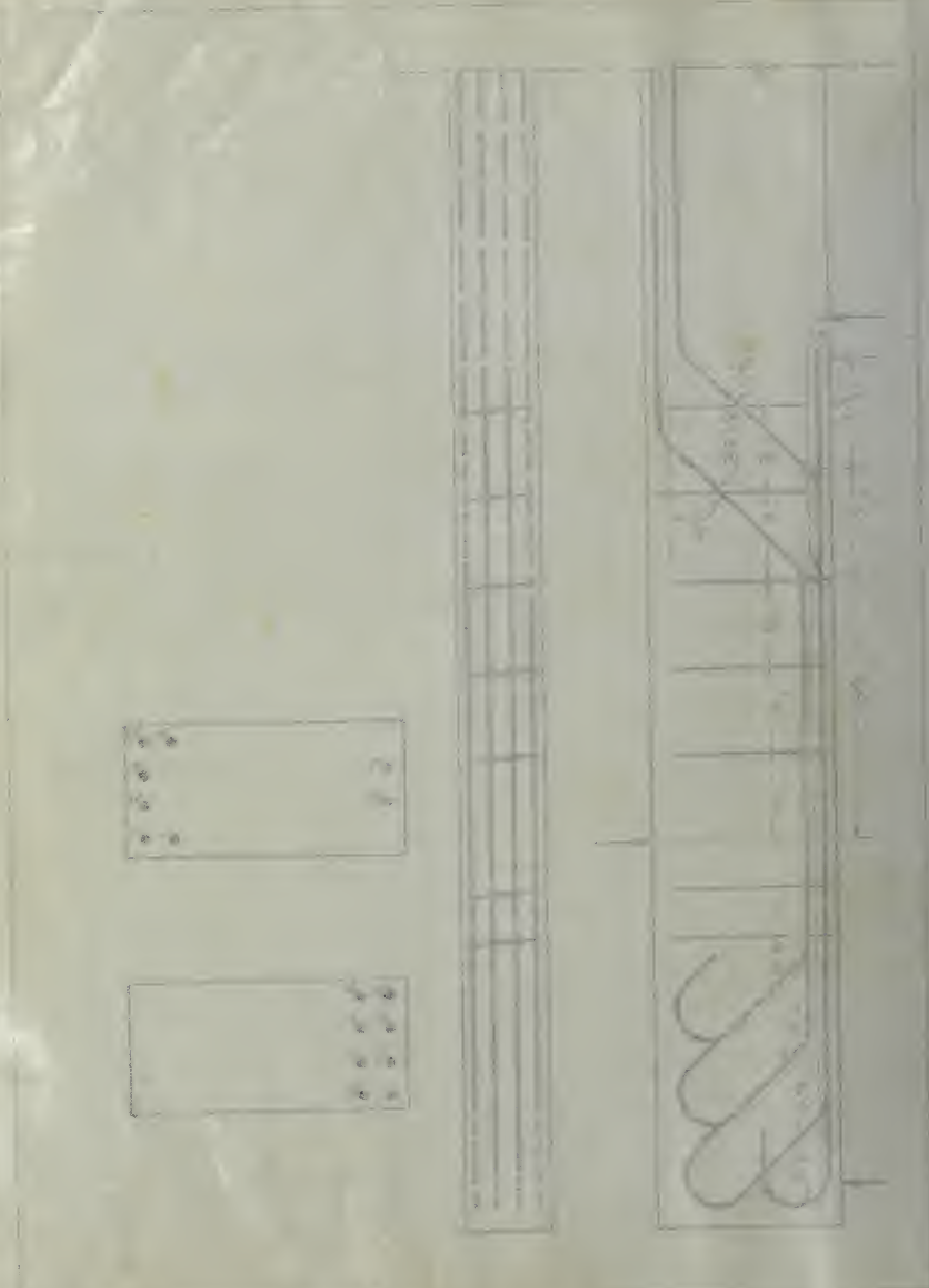
Beam 396-1



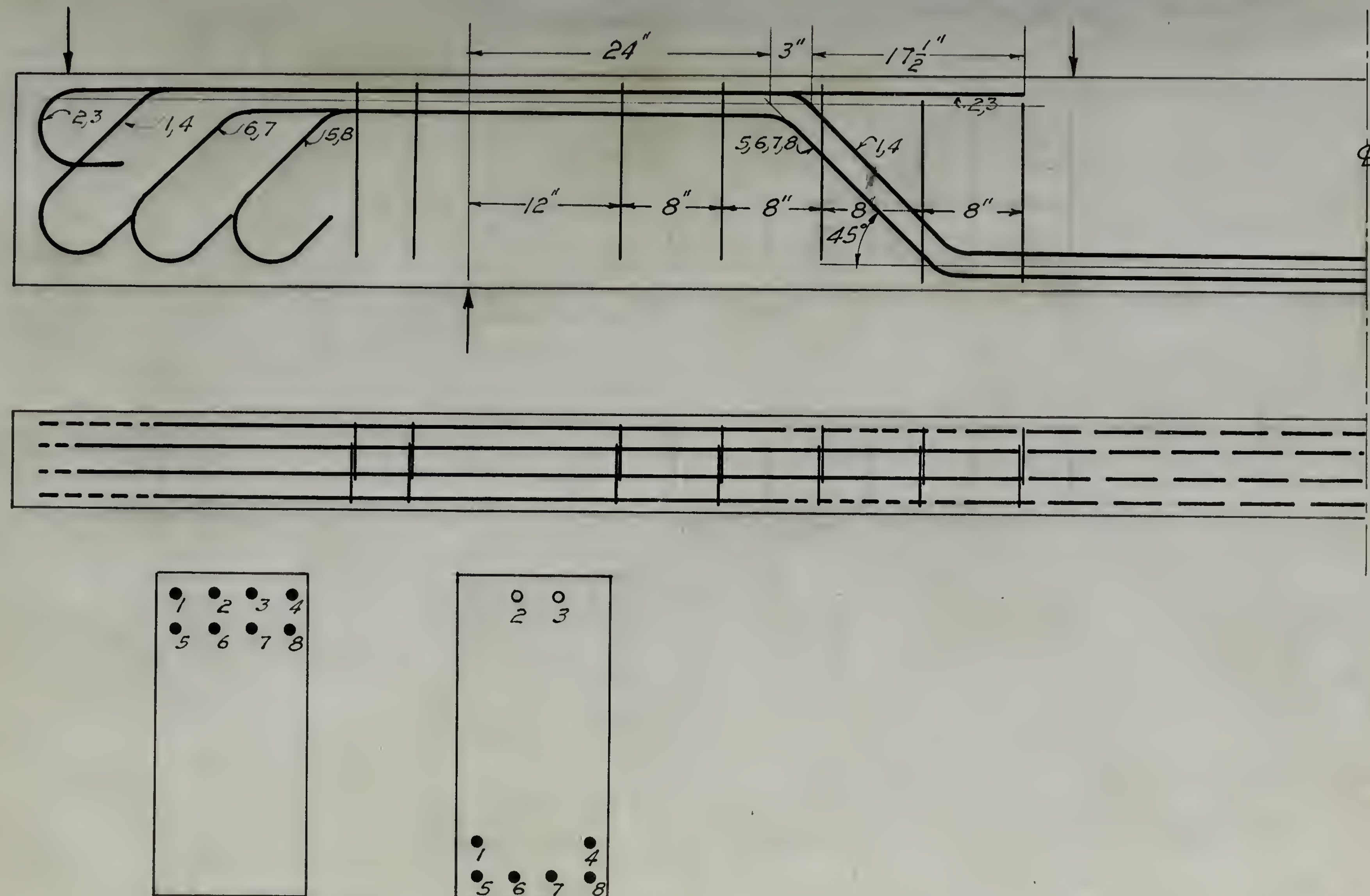


Beam 396-2

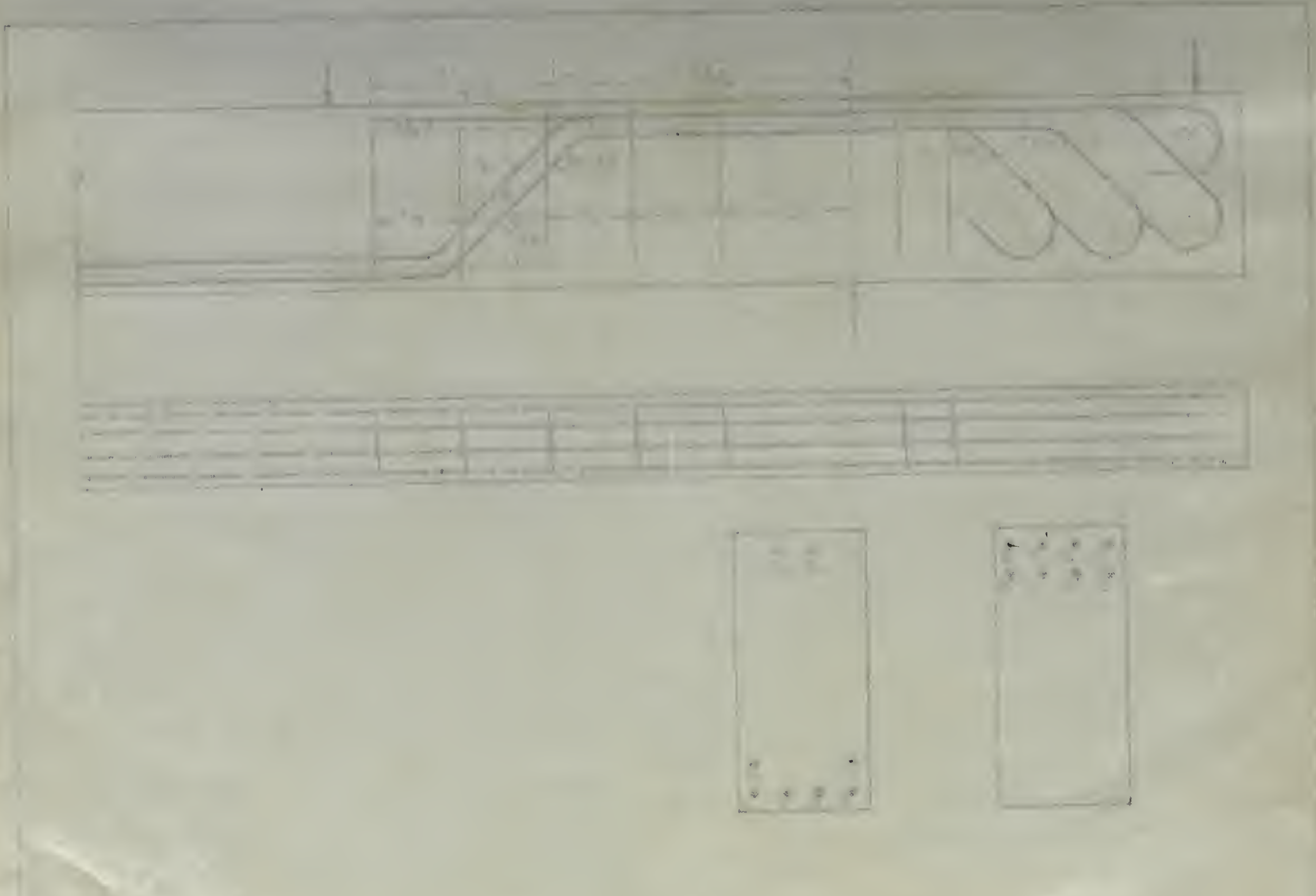




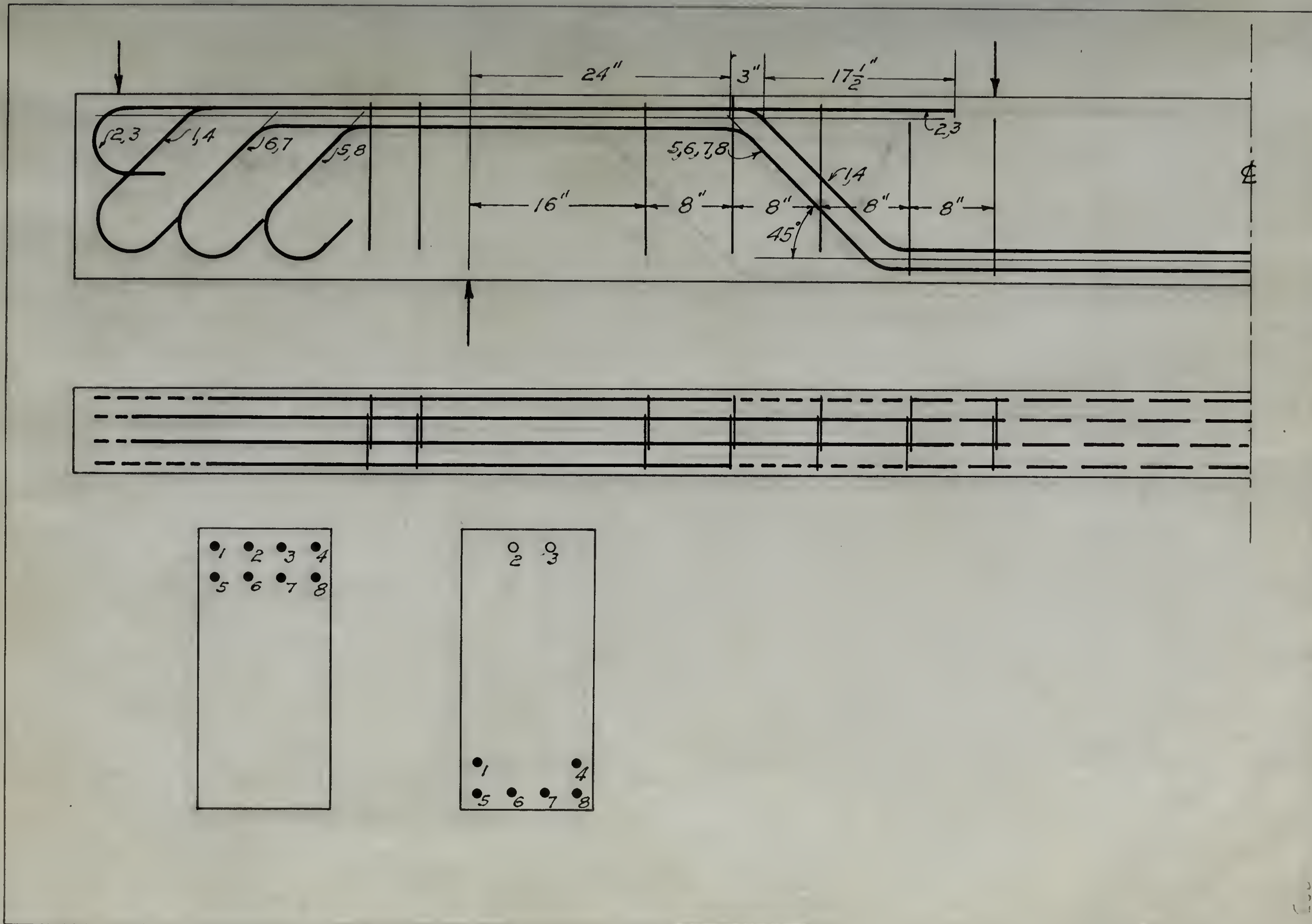
Beam 397

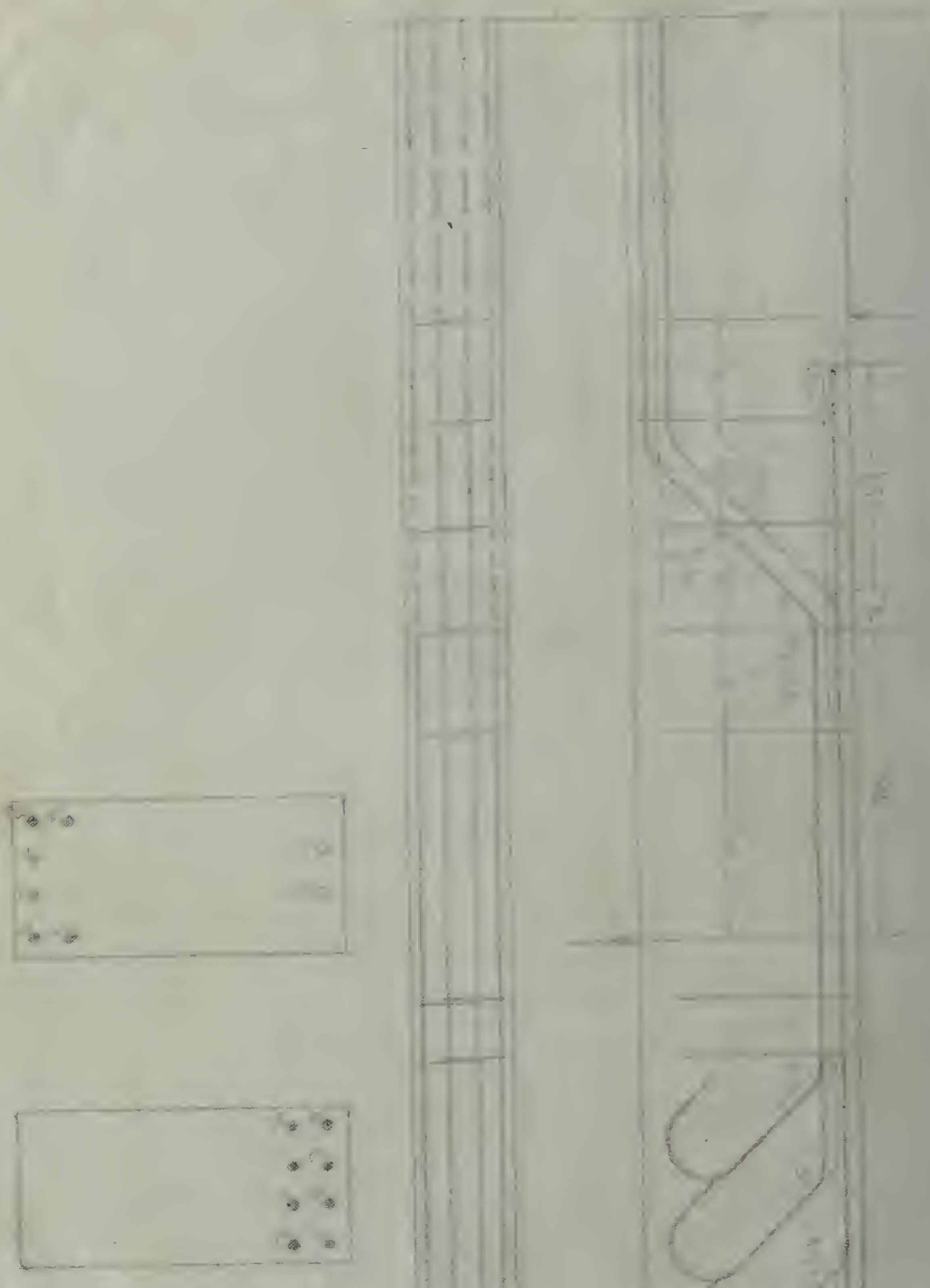


24"
3"
$17\frac{1}{2}$"
2,3
1,4
6,7
5,8
5,6,7,8
1,4
2,3
12"
8"
8"
8"
8"
45°
1 2 3 4
5 6 7 8
2 3
1 4
5 6 7 8

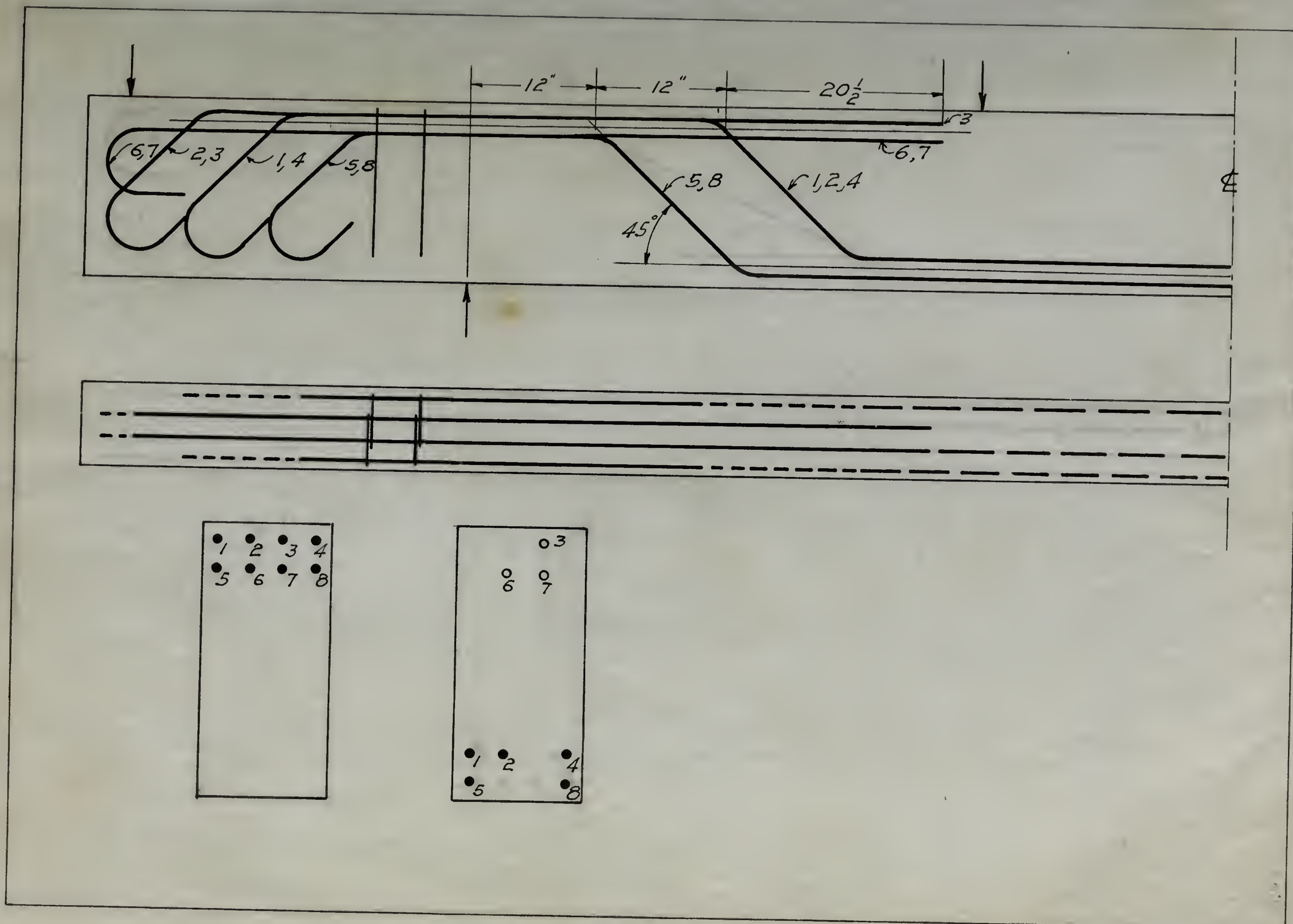


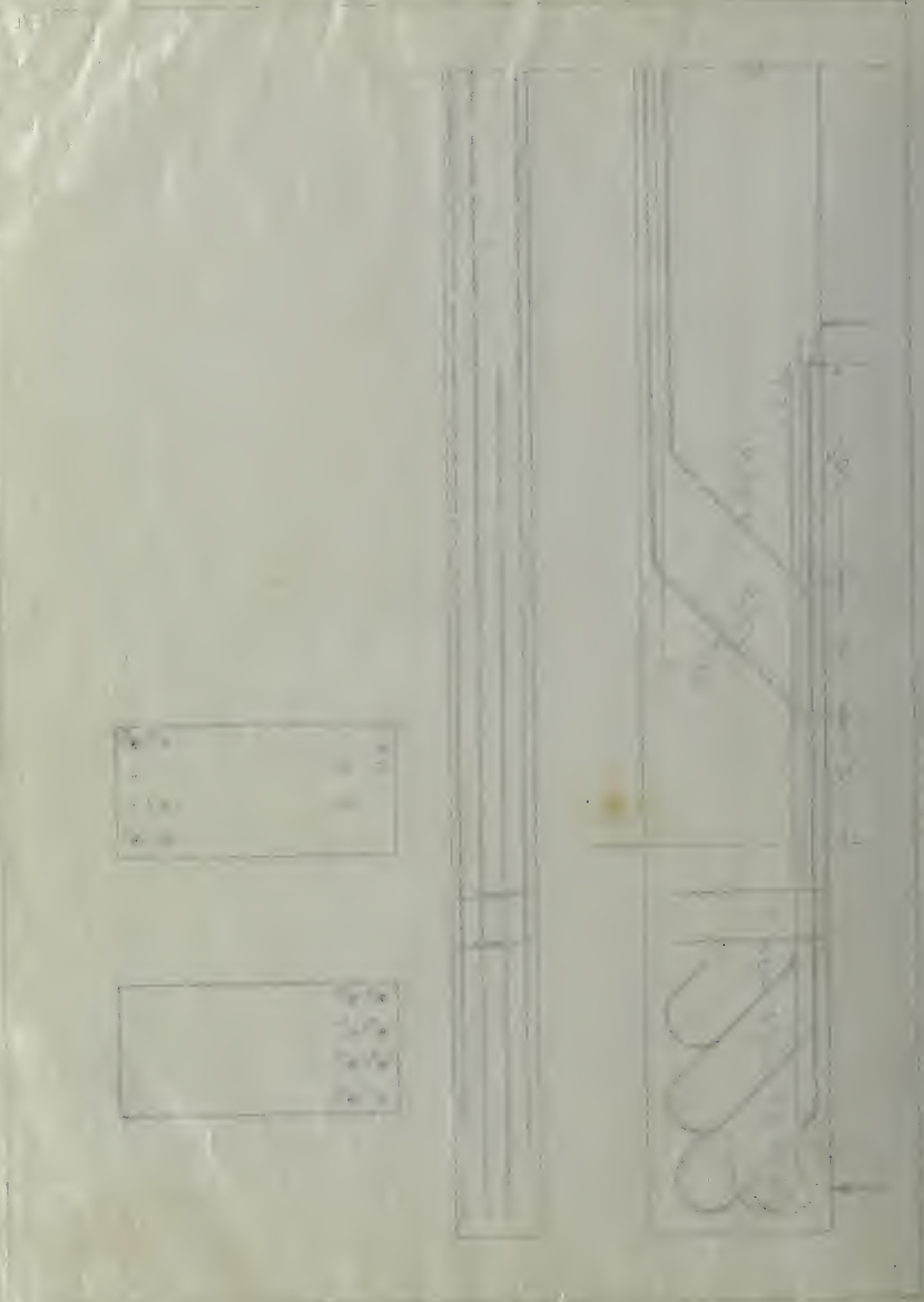
Beam 398



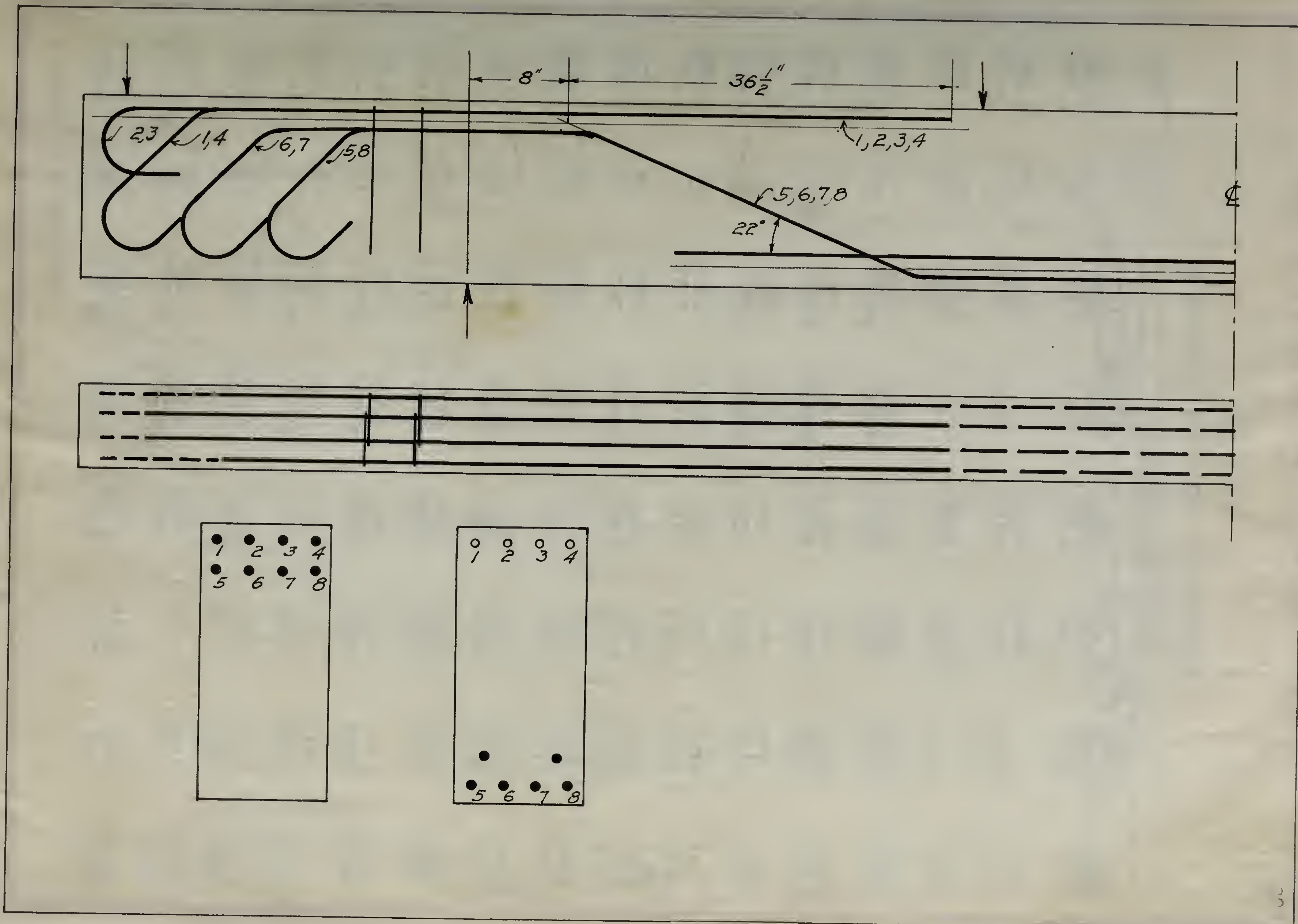


Beam 399





Beam 400



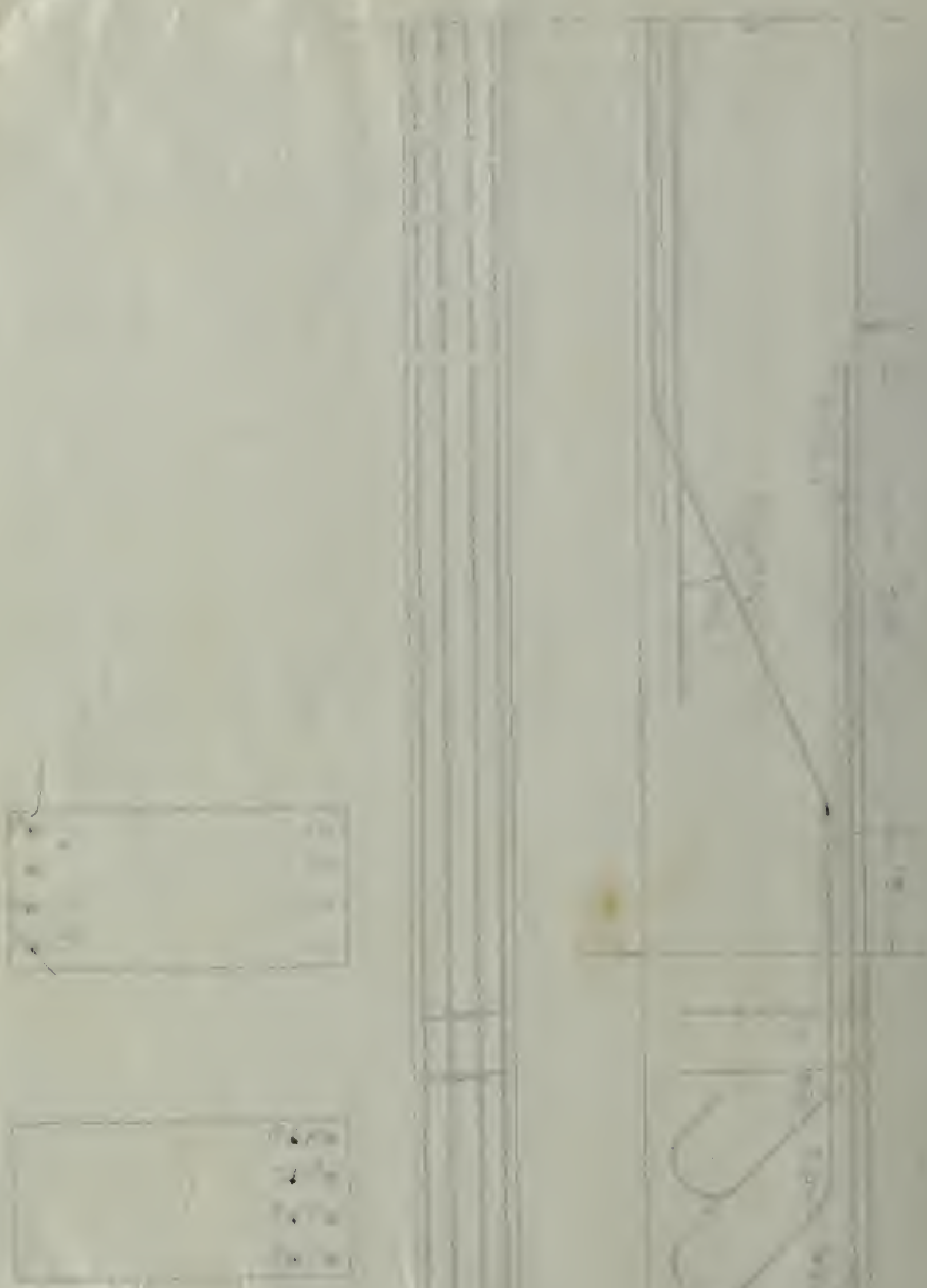


TABLE 5.

COMPRESSIVE STRENGTH OF CYLINDERS.

Beam No.	Age Days.	Cylinders Stored.					
		In Sand.			With Tears.		
		8x16 in.	6x12 in.	Av.	8x16 in.	6x12 in.	Av.
380.1	63	2830	2900	2865	3130	2990	3060
380.2	59	3815	4010	3912	3810	3520	3665
381.1	61	3250		3250	3070		3070
381.2	62	3695	3690	3692	3280	3490	3385
382.1	59	3305		3305	3315		3315
382.2	59	3030	3210	3120	2590	2905	2748
383.1	64	3125	3220	3172	2985	3180	3082
383.2	60	2855*	3140*	2998	2690	3210	2950
384.1	64	3280	3140	3210	2970	3190	3080
384.2	57	3580*	3695*	3638	3090	3795	3442
385.1	57	2965	3045	3005	3200	2770	2985
385.2	58	3570*	3850*	3710	3220	3505	3362
386.1	66	3060	3000	3030	3170	2570	2870
386.2	60	3710	3230	3470	3520	3530	3525
387.1	62	3090	3445	3268	3375	3420	3348
387.2	61	3050	3120	3085	2860	3070	2965
388.1	64	3705	3580	3642	3430	3090	3260
388.2	59	3245	3160	3202	3000	2940	2970
389.1	63	3640	3420	3530	3275	3145	3210
389.2	62	2970	3460	3215	3100	3105	3102
390.1	62	3110	2830	2970	3020	2790	2905
390.2	64	3435	2710	3072	2900	2570	2735
391.1	62	2970	3400	3185	2870	2915	2892
391.2	61	3420*	4000*	3710	3440	3550	3495
392.1	61	3125	3340	3232	2455	3180	2818
392.2	60	3290*	3350*	3320	2890	2700	2795
393.1	62	3230	3070	3150	2995	3315	3155
393.2	63	3110	2645	2878	2390	2260	2325
394.1	62	3515	3220	3368	3325	2965	3145
394.2	60	3690*	3790*	3740	3270	3440	3355
395.1	62	3115	3110	3112	2950	3290	3120
395.2	61	3240*	3380*	3310	2990	3040	3015

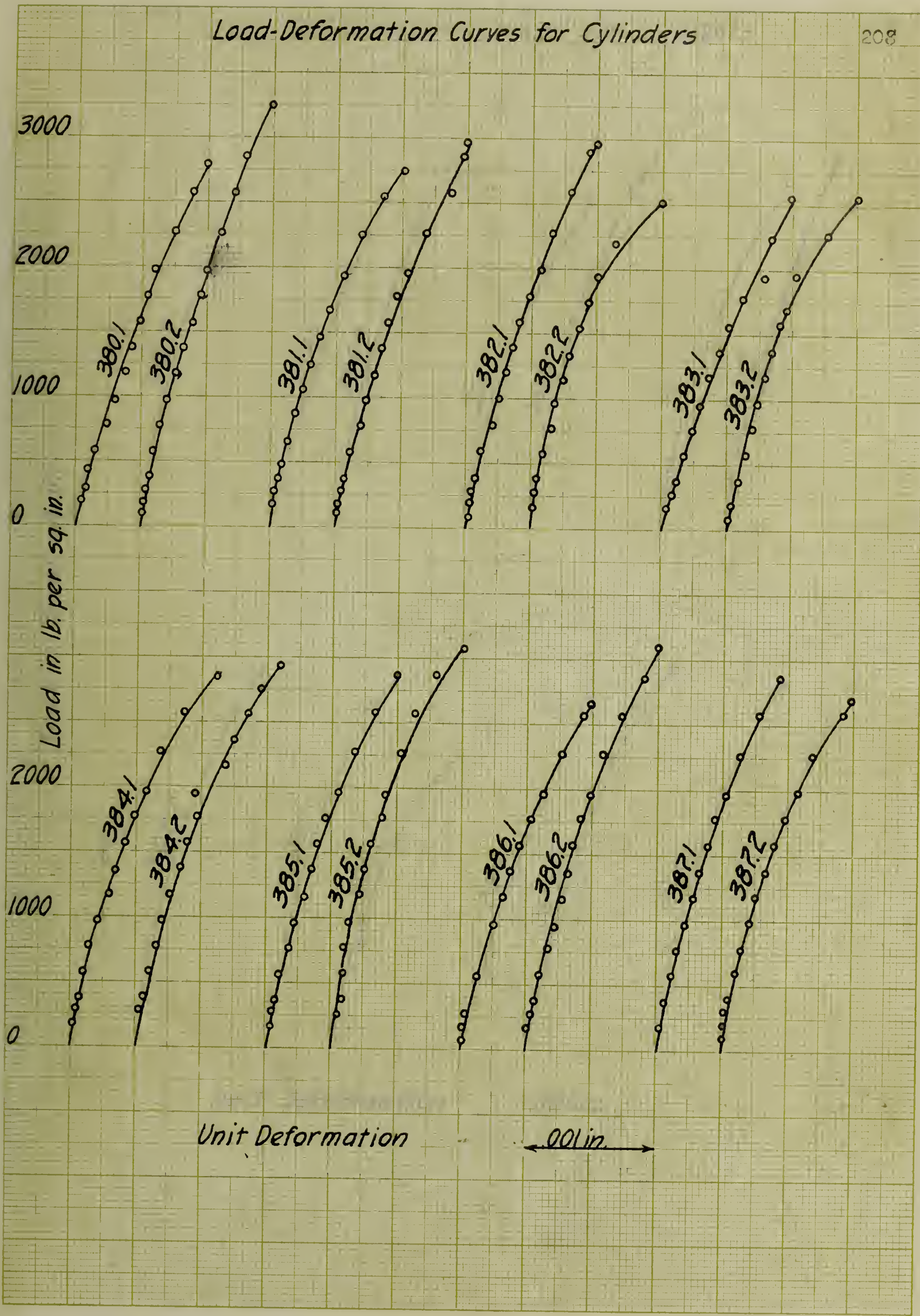
* Stored in damp room.

TABLE 5 CON'T.

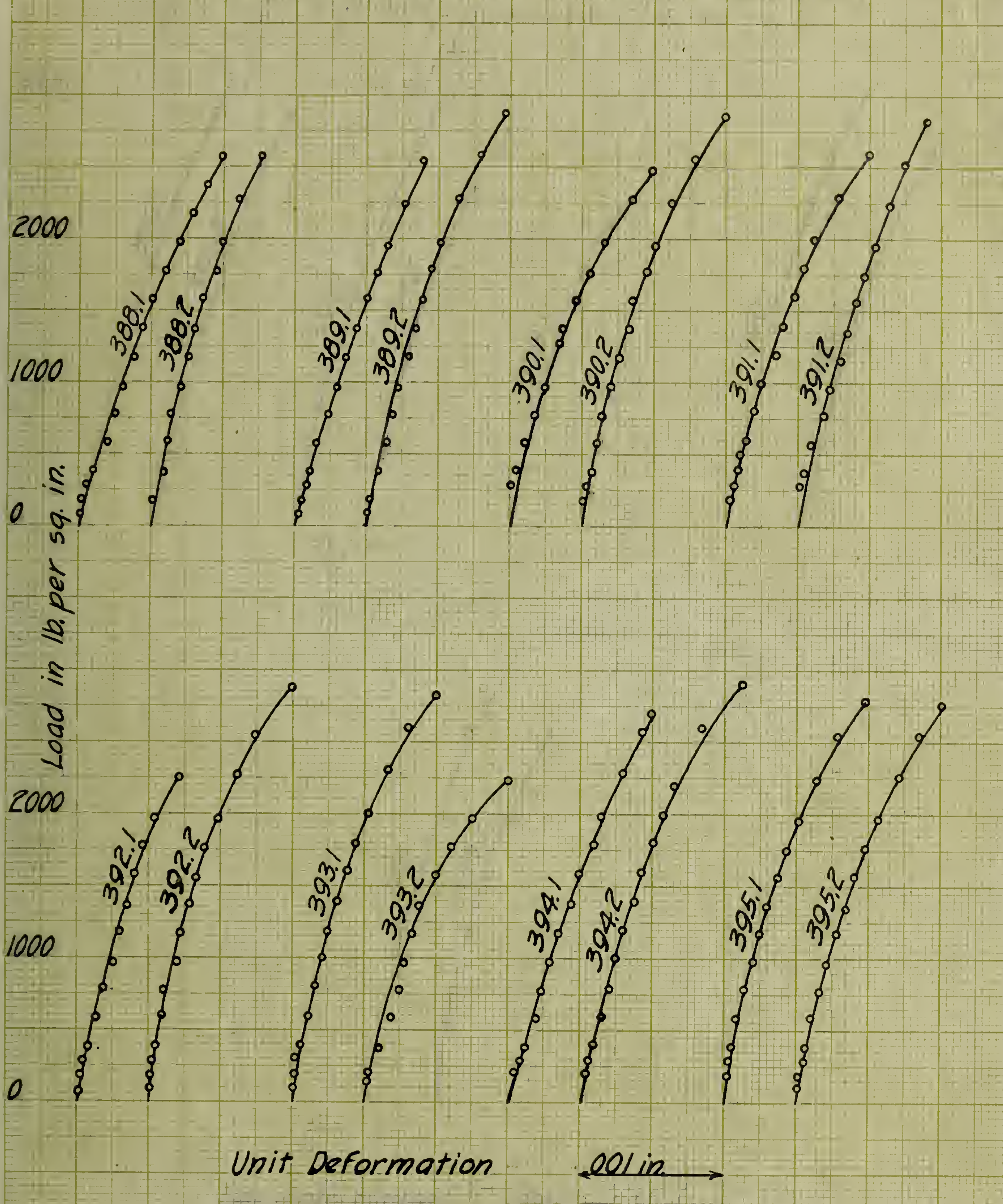
COMPRESSIVE STRENGTH OF CYLINDERS.

Beam No.	Age Days.	Cylinders Stored.					
		In Sand.			With Beams.		
		8x16 in.	6x12 in.	Av.	8x16 in.	6x12 in.	Av.
396.1	61	3485		3485	3410		3410
396.2	61	3660*	3770*	3715	3430	3295	3362
397.1	60	3155	3100	3128	3440	3030	3235
397.2	61	3280	2810	3045	2920	2445	2682
398.1	64	2495	3225	2860	2530	2835	2682
398.2	59	3485	3340	3412	3030	2950	2990
399.1	60	3565	3105	3335	3165	3540	3352
399.2	61	3035* 20	3050*	3035	2940	2680	2810
400.1	61	3580	3500	3540	3335	2980	3158
400.2	59	3520*	2675*	3098	2845	3485	3165

av. $\varepsilon E_1 = .67\, f_c$


Load-Deformation Curves for Cylinders
3000
2000
1000
0
380.1
380.2
381.1
381.2
382.1
382.2
383.1
383.2
Load in lb. per sq. in.
2000
1000
0
384.1
384.2
385.1
385.2
386.1
386.2
387.1
387.2
Unit Deformation
.001 in.

Load-Deformation Curves for Cylinders



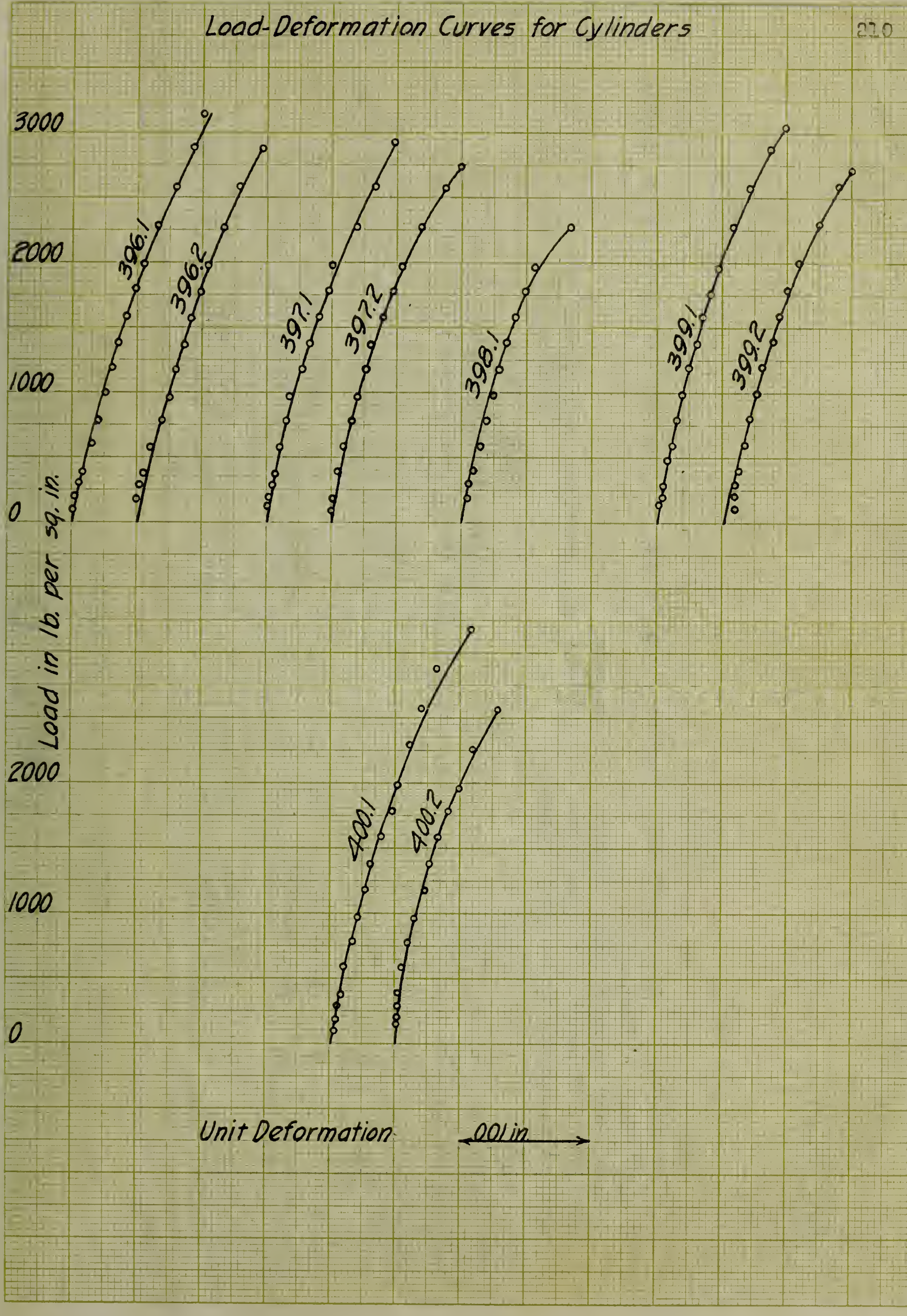

Load-Deformation Curves for Cylinders
3000
2000
1000
0
396.1
396.2
397.1
397.2
398.1
399.1
399.2
Load in lb. per sq. in.
2000
1000
0
400.1
400.2
Unit Deformation
.001 in.

TABLE 6

DATA OF BEAMS AND SUMMARY OF RESULTS

Av.														422			
397·1	63	45°	6	3/8"ϕ Vertical					4	2*		3	192 500	482	3128	3235	T., Cr. U. Bds.
397·2	61	45°	6	Stirrups+					4	2*		3	179600	434	3045	2682	do.
Av.	62													458			
398·1	60	45°	6	3/8"ϕ Vertical					4	2*		3	168000	398	2860	2682	D.T.
398·2	60	45°	6	Stirrups+					4	2*		3	173100	420	3412	2990	T. and D.T.
Av.	60													409			
399·1	60	45°	5		2				3			12	176100	423	3335	3352	T., Cr. U. Bds. & D.T.
399·2	60	45°	5		2				3			12	184900	449	°3035	2810	T., Cr. U. Bds.
Av.	60													436			
400·1	60	22°	4		4								151000	364	3540	3158	D.T.
400·2	59	22°	4		4								149700	365	°3098	3165	D.T.
Av.	59													364			

* Bars bent down 27 in. from support.
\+ Stirrup spacing 8 in. See drawing of beam for location of stirrups.
△ Bars placed 34 in. from support by mistake.
⊙ Stored in moist room.
T, Tension D.T.,- Diagonal Tension B, Bond Cr. U. Bds., Crushing under bends

Table 6

Data of Beams and Summary of Results

Beam No.	Age in Days	Angle of Bend	No. of Bars Bent Down	Number of $\frac{5}{8}$" φ Bars Bent Down and Distance from Support in Inches: 8	12	14	16	20	24	28	32	Spacing Inches	Maximum Applied Load Pounds	Maximum Shearing Stress Lb. per Sq. In.	Unit Load on Cylinders: Sand Stored	With Beam	Manner of Failure
380.1	63		None										102 800	246	2865	3060	D.T.
380.2	59												104 000	254	3912	3665	D.T.
Av.	61													250			
381.1	61	45°	6						4	2*		3	165 000	401	3250	3070	Cr. U. Bds. & D.T.
381.2	61	45°	6						4	2*		3	124,100	299	3692	3385	D.T.
Av.	61													350			
382.1	62	22°	5	2				3				12	175 500	422	3305	3315	T. followed by D.T.
382.2	60	22°	5	2				3				12	183 700	443	3120	2748	T., Cr. U. Bds., & D.T.
Av.	61													432			
383.1	63	32½°	6	2				2			2	12	183 200	441	3172	3082	T.
383.2	60	32½°	6	2				2			2	12	181 500	441	°2998	2950	T., Cr. U. Bds., & D.T.
Av.	62													441			
384.1	63	45°	6	2				2			2	12	176 700	429	3210	3080	T., Cr. U. Bds., & D.T.
384.2	59	45°	6	2				2			2	12	178 600	440	°3638	3442	do
Av.	61													434			
385.1	63	32½°	5	2				3				12	176 300	422	3005	2985	T., Cr. U. Bds
385.2	59	32½°	5	2				3				12	190 000	456	°3710	3362	T., at supports and center.
Av.	61													439			
386.1	62	32½°	6	2			2		2			8	188 200	458	3030	2870	T., Cr. U. Bds.
386.2	60	32½°	6	2			2		2			8	188 000	453	3470	3525	do
Av.	61													456			
387.1	62	32½°	5	2					3			16	182 300	428	3268	3398	T., Cr. U. Bds. & D.T.
387.2	61	32½°	5	2					3			16	168 400	403	3085	2965	T. followed by D.T.
Av.	62													416			
388.1	62	32½°	4			4							173 800	411	3642	3260	T. B. & Cr. U. Bds.
388.2	60	32½°	4			4							143 200	343	3202	2970	B. & D.T.
Av.	61													377			
389.1	62	32½°	4			4	3/8" φ Stirrups						174 000	422	3530	3210	T. and D.T.
389.2	61	32½°	4			4	(See Drawing of beam)						169 000	416	3215	3102	T.
Av.	62													419			
390.1	62	45°	8	2			2		2		2	8	181 200	450	2970	2905	T., Cr. U. Bds.
390.2	58	45°	8	2			2		2		2	8	186 000	459	3072	2735	do.
Av.	60													454			
391.1	60	32½°	6		2			2		2		8	187 800	440	3185	2892	T.
391.2	59	32½°	6		2			2		2		8	172 000	421	°3710	3495	T. and D.T.
Av.	60													430			
392.1	61	32½°	6				2		2		2	8	146 400	352	3232	2818	D.T.
392.2	61	32½°	6				2		2		2	8	176 400	430	°3320	2795	T. and D.T.
Av.	61													391			
393.1	61	45°	6	2			2		2			8	164 000	397	3150	3155	T., Cr. U. Bds.
393.2	61	45°	6	2			2		2			8	170 000	410	2878	2325	T. and D.T.
Av.	61													404			
394.1	59	45°	6		2			2		2		8	172 300	410	3368	3145	T., Cr. U. Bds.
394.2	60	45°	6		2			2		2		8	785 400	457	°3740	3355	do
Av.	60													434			
395.1	60	45°	6				2		2		2	8	180 600	434	3112	3120	T., Cr. U. Bds. & D.T.
395.2	61	45°	6				2		2		2	8	167 000	408	°3310	3015	do.
Av.	60													421			
396.1	59	45°	6	3/8" φ Vertical					4	2*		3	182 600	443	3485	3410	T., Cr. U. Bds.
396.2	60	45°	6	Stirrups+					4	2△		3	165 000	402	°3715	3362	(See notes of test)
Av.														422			
397.1	63	45°	6	3/8" φ Vertical					4	2*		3	192 500	482	3128	3235	T., Cr. U. Bds.
397.2	61	45°	6	Stirrups+					4	2*		3	179 600	434	3045	2682	do.
Av.	62													458			
398.1	60	45°	6	3/8" φ Vertical					4	2*		3	168 000	398	2860	2682	D.T.
398.2	60	45°	6	Stirrups+					4	2*		3	173 100	420	3412	2990	T. and D.T.
Av.	60													409			
399.1	60	45°	5		2				3			12	176 100	423	3335	3352	T., Cr. U. Bds. & D.T.
399.2	60	45°	5		2				3			12	184 900	449	°3035	2810	T., Cr. U. Bds.
Av.	60													436			
400.1	60	22°	4		4								151 000	364	3540	3158	D.T.
400.2	59	22°	4		4								149 700	365	°3098	3165	D.T.
Av.	59													364			

* Bars bent down 27 in. from support.
\+ Stirrup spacing 8 in. See drawing of beam for location of stirrups.
△ Bars placed 34 in. from support by mistake.
° Stored in moist room.
T, Tension   D.T., Diagonal Tension   B, Bond   Cr. U. Bds., Crushing under bends